Does the energy intensive industry obtain windfall profits through the EU ETS?

An econometric analysis for products from the refineries, iron and steel and chemical sectors

Research commissioned by the European Climate Foundation

Author(s):
Sander de Bruyn
Agnieszka Markowska
Femke de Jong
Mart Bles

In cooperation with Marc de Leeuw, Mathijs Gerritsen and Adriaan Braat

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Further information on this study can be obtained from the contact person Sander de Bruyn.

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Preface

This research started in the Summer of 2009. The European Commission had then just published the criteria that would decide whether sectors would qualify for free allocation post 2012 in the amended EU ETS directive. A few 'back-of-the-envelope' calculations already showed then that virtually all of the energy intensive industry in the EU would qualify for free allocation.

This result was remarkable for a few reasons. First, the electricity producers were going to be put under an auctioning regime because the Commission was convinced that the power sector was making windfall profits during Phase 1 and Phase 2 of the EU ETS but no single study has been undertaken to investigate whether the energy intensive industry had made windfall profits. The free allocation was therefore purely granted on the belief that energy intensive sectors could not pass through the costs of auctions into the product prices. Second, economic theory tells us that most company decisions at the margin are similar for grandfathered or auctioned emission credits. Therefore, if auctioning would result in carbon leakage, there is a severe risk that the same would hold for free allocation. Only if companies would not pass through the opportunity costs of their freely obtained allowances in the product prices, there would be a difference between free allocation and auctioning in this case.

With these 'observations' in mind, the European Climate Foundation was willing to finance a research proposal which constitutes the first ex-post cost-pass-through analysis of several energy intensive sectors that have to comply to the EU ETS. This research was conducted by CE Delft. We like to thank especially Jules Kortenhorst and Stephen Boucher from the European Climate Foundation to make this research possible and supporting us when needed. Useful comments from Stephen Boucher were included in the final version. We also like to thank Tomas Wyns from Climate Action Network for believing in the value added of this research and supporting us when needed. We like to thank the three Amsterdam-based econometricians Marc de Leeuw, Matthijs Gerritsen and Adriaan Braat for supporting us with the econometric estimations and devising the estimation procedure as outlined in Figure 4 of this report. Finally we like to thank Jos Sijm from ECN and Maartje Sevenster, Femke Brouwer, Marisa Korteland and Harry Croezen for CE Delft for helping us with some technical, economic and environmental details of the markets and sectors under scrutiny.

Contents

Summary

Emission trading schemes belong to the most efficient and effective policy options to achieve a given emission reduction target. In an emission trading system, each source of pollution gets a certain amount allowances that give the 'right' to emit one unit of pollution. By reducing the amount of allowances issued, the system can achieve emission reductions among its participants. By allowing the allowances to be traded on an organized exchange, the market assures that these reductions are achieved at the least possible cost for participants.

In theory, the efficiency of the system is achieved regardless of the initial allocation method. Allocation methods most often considered are auctioning and free allocation. Because free allocation impacts less on the costs for companies, it is believed to be a better system in the context of unilateral climate policies. Through free allocation, companies face less cost disadvantages compared to producers that do not fall under a climate policy regime. Free allocation would therefore have less distortive impacts on trade and economic growth – allowing EU producers to compete at lower price levels than would be possible under an auctioning regime.

However, this belief in the benefits of free allocation crucially hinges on the assumption that companies do not pass through the opportunity costs of their freely obtained allowances in the product prices. **If they would pass through the market value of the freely obtained allowances, product prices would rise and the impacts on trade and competitiveness of a system of free allocation would be similar to that of auctioning. The only effect of free allocation would then be that companies gain windfall profits through the emission trading system and income from citizens will be transferred to business.** This would be a particularly unfavourable outcome in the European context, where free allocation is presented as a solution towards carbon leakage.

Economic theory tells us that companies will pass through the costs of the freely obtained allowances in most circumstances – even if this will bring them a competitive disadvantage to producers not due to climate policies. According to economic theory, companies are profit-maximizing institutions that prefer profitability on invested capital over maintaining market shares. If passing through the opportunity costs in product prices can enhance their profitability, they will do so even if this would bring them some harm in terms of loss of market shares, as long as the additional profits do outweigh the additional costs. How much the firms will be able to pass the costs on depends on market structure and on elasticity of demand and supply. Theoretical analysis shows that typically, assuming linear demand and supply curves, the firms will be able to pass from 50% of increase in marginal costs due to the EU ETS (under the monopoly) to a 100% (under perfect competition). How much the increase in marginal costs reflects the carbon price depends on elasticity of supply and demand. Assuming non-linear demand and supply curves implies different rules and a possibility to pass on more than a 100% of additional costs due to the EU ETS.

We have tested the hypothesis that energy intensive companies did not pass through the costs of their freely obtained allowances during Phase 1 and Phase 2 of the European emission trading system the EU ETS. The EU emissions trading scheme (EU ETS) was launched in 2005 to cap CO_2 emissions from large

industrial facilities and electricity producers. Covering over 10,000 installations, it is the largest international emission trading system in the world. During Phase 1 (from 2005-2007) and Phase 2 (from 2008 till 2012), allowances were issued for free to the energy intensive industries in all member countries. The question is whether the value of these free allowances have been forwarded in the price of EU products, signalling windfall profits, or that EU producers did not do that.

This is investigated using econometric methods stemming from the concept of co-integration and market integration. The idea is that several dependencies exist between EU and non-EU markets through the prices of inputs in production processes and the prices of outputs on the various markets. If, for instance, prices of iron ores increase in Asia, they are likely to start to increase in Europe as well. This will put an upward pressure on the price of steel in both Europe and Asia. If Asian steel prices increase due to local shortages, this will also put an upward pressure on European steel prices as a larger portion of European steel will be shipped to Asia. In this system of market dependencies, it can then be investigated if the price of an emission allowance at the European ETS market is a significant variable for the variation in prices between EU and non-EU products over time.

A standardized estimation procedure was developed (co-developed and reviewed by three independent econometricians) in order to come up with robust outcomes (and preventing data mining and spurious outcomes). This estimation procedure was subsequently applied to a few selected products from the iron and steel, refineries and (petro)-chemical industries. For these products, prices were compared between the EU and the US and it was investigated to what extent European prices were influenced by price developments on the EU ETS markets.

The outcomes of the econometric analyses show that for most products a significant influence of the EUA prices on the European product prices can be found. For products from the refineries sectors (gasoil, diesel and gasoline) a quite direct influence can be found. Within two weeks are higher prices on the EU ETS markets translated into higher prices on the German markets for diesel and gasoline. For gasoil traded in Rotterdam an immediate price increasing effect from CO_2 prices can be found. For the products of the iron and steel sectors (hot and cold rolled coil), a significant influence of CO_2 prices can be found after one month, while for polyethylene, polystyrene and polyvinylchloride a delayed influence from 3-8 weeks can be found.

The cost-pass-through rates from the econometric estimations show that for products of the refineries sector full cost-pass-through rates are likely. The econometric results even suggest that more than 100% of the costs were passed through, but this cannot be stated with certainty. For both steel varieties, the cost-pass-through was close to 100%. The same value was found for polyvinylchloride and polyethylene. For polystyrene the cost-pass-through rate was significant but much lower at 33%.

These results cannot be directly interpreted in amount of windfall profits, as we have no information on the individual emissions stemming from producing these products. However, if the full cost-pass-through rates would prevail for all products in the refineries and iron and steel sectors, it can be calculated that the total amount of windfall profits would equal € 14 billion between 2005 and 2008. This implies a substantial transfer of money from consumers to the energy intensive industry.

This research hence results in the conclusion that **there is ample evidence that the energy intensive industry has passed through the prices of their freely obtained allowances during Phase 1 and Phase 2 of the EU ETS. This has generated windfall profits in these sectors.** The cost price increase is identical as it would have been under an auctioning regime but without the possibility that governments would have to compensate consumers by recycling auction revenues. Politicians seem to have underestimated the potential of windfall profits in exposed sectors and have believed overall the claims of industry that additional costs cannot be passed through. The higher prices on the EU markets may have stimulated imports from non-EU producers but this was not quantitatively assessed in this study. The results, however, do point at the suggestion that free allocation falls short of its intentional goals: to prevent carbon leakage. Under free allocation both windfall profits and carbon leakage may be stimulated.

1 Introduction

1.1 Background

The EU emissions trading scheme (EU ETS) was launched in 2005 to cap CO_2 emissions from large industrial facilities and electricity producers. It covers approximately 10,000 energy intensive installations across the EU, which represent close to half of Europe's emissions of CO_2. These installations include steel factories, power plants, oil refineries, paper mills, and glass and cement installations. Each installation gets a certain amount of European Union Allowances (EUAs) that give the 'right' to emit one tonne of Carbon Dioxide equivalent. By reducing the amount of allowances issued, the EU ETS can achieve emission reductions among its participants. By allowing the EUAs to be traded on an organized exchange, the market assures that these reductions are achieved at least cost for participants.

The EU ETS currently helps EU Member States achieve compliance with their commitments under the Kyoto Protocol. After 2012, the 3rd Phase of the EU Emissions Trading Scheme (the EU ETS) comes into place that lasts until 2020. New to this system is the European harmonized allocation of allowances. However, a fierce debate was held whether these allowances should be distributed free of charge, or whether they should be auctioned to the owners of the installations. Auctioning was in principle believed to be a better system yielding a higher degree of efficiency and therefore lower CO_2 emission prices. However, industry feared auctioning would deteriorate their competitive position and plead largely for free allocation of rights.

This debate finally resulted in the outcome where emissions from electricity production largely fall under an auctioning regime, whereas most emissions from industrial installations would fit for free allocation of allowances. This outcome was backed by studies that showed that electricity production had passed the costs of their freely obtained allowances through in the price of their products during Phase 1 and Phase 2 of the emission trading system (Sijm *et al.*, 2005 and Sijm *et al.*, 2008). Such ex-post studies were lacking for industrial products. Instead, the literature has been abundant with studies that took an ex-ante perspective, hypothesizing whether they *might* be able to pass on the costs. As a literature review by CE Delft (2008) showed, the results from these studies were so mixed that it was almost impossible to derive any relevant conclusion on whether industry might be able to pass through the costs of their EUAs.

This study aims to provide an ex-post perspective to the question whether industry has passed through the costs of their freely obtained allowances into the product prices. In doing so, this study is similar in philosophy to the studies by Sijm *et al.* (2005, 2006 and 2008) although data and estimation methods differ.

1.2 Aim of this study

To provide an ex-post analysis whether selected industries have passed through the costs of their freely obtained allowances during Phase 1 and Phase 2 of the EU ETS.

1.3 Approach and delineation

The ex-post analysis is conducted with the aim of econometric time-series analysis. Econometrics is the science that combines economic theory with statistics to analyze and test economic relationships. Although many econometric methods represent applications of standard statistical models, there are some special features of economic data that distinguish econometrics from other branches of statistics. Economic data are generally observational, rather than being derived from controlled experiments. Moreover, the observed data tend to reflect complex economic equilibrium conditions where individual influences cannot be singled out. Consequently, the field of econometrics has developed methods for identification and estimation of simultaneous equation models. These methods allow researchers to draw conclusions on the nature of the economic processes they tend to observe.

This study uses econometrics to analyze the price movements in markets in some selected products, both in the EU and non-EU in combination with price movements in the CO_2 markets. The selected products are: gasoline, diesel, hot rolled coil, cold rolled coil, polystyrene, polyethylene and polyvinylchloride. This study therefore analyzes the possibilities to pass through the costs in the sectors refineries, iron and steel and chemicals. Although in principle more products and sectors could be analyzed with the current framework, time, financial constraints and data limitations did prevent us to provide a more complete picture. For cement, for instance, it proved impossible to conduct this analysis because no uniform data are being collected of cement prices worldwide.

This study will only focus on the possibility that the costs of the freely obtained allowances are passed through in the product prices in EU markets. This may lead to higher prices at the EU markets. Eventual consequences from these higher prices, such as increase in imports, higher profits, attracting foreign investments in energy intensive production units, will not be taken into account.

The ex-post analysis runs from the start of the EU ETS in 2005 until September 2009. Price data after that period were available but were not included as the data collection process took place in October. As this proved to be a somewhat time-consuming procedure, we have decided not to update the prices to more recent months. Updates could be planned in future research.

1.4 Content

This report is structured as follows: Chapter 2 presents an outline of the concept of cost-pass-through and windfall profits. Definitions of both concepts and a theoretical background are provided on the likeliness that companies pass through the opportunity costs of their freely obtained allowances, as well as a literature review as to whether unilateral environmental policies result in adverse impacts on competitiveness and trade flows.

Chapter 3 presents the empirical background of this study, the estimated models and the data used. Chapter 4 discusses cost-pass-through in the steel sector. Chapter 5 presents an analysis for the refineries sector and Chapter 6 for the (petro-) chemical sector. General conclusions and policy recommendations are presented in Chapter 7.

2 Theoretical framework

2.1 Introduction

This chapter outlines the theoretical framework of cost-pass-through and the allocation of emission credits. First we will elaborate on the allocation of emission credits in an emission trading scheme and discuss the short- and long-term consequences of the two main allocation methods: grandfathering and auctioning. In the subsequent section, a neoclassical treatment will be given of the possibilities to pass through the costs. This gives the short-term eventual impacts of an emission trading system on price formation of markets and profits of firms. Then, in the final section, we will elaborate on the potential long-term impacts of an emission trading system through the Porter hypothesis.

2.2 The EU ETS, allocation and efficiency

In theory, systems of tradable emission allowances belong to the most efficient and effective policy options to achieve a given emission reduction target. Their effectiveness is based upon two principles. First, the costs per ton of emission reduction differ from measure to measure, from company to company, and from one economic sector to another. Second, governments lack the information as well as the manpower to prescribe only the cheapest options from all possible measures with which the environmental targets can be achieved. A system of tradable emission allowances solves the latter problem by using the power of the market. In the market, every participant makes optimal use of the information about the possibilities within the own company to maximize profits. By giving a financial value to emissions and creating a market where they can be traded, emission reductions are achieved - as by an 'invisible hand' - against the lowest costs.

In theory, the efficiency of the system is achieved regardless the initial allocation method (Tietenberg, 1984). Hence, whether the rights are being auctioned or being grandfathered only matters for the distribution of the costs, not for the efficiency of the system. However, this claim is only valid for pure forms of grandfathering or auctioning (CE, 2008a).[1] Under the realms of the current emission trading system in Europe, it can be proved that auctioning is actually a more efficient system than grandfathering (Climate Strategies, 2007; Demailly and Quirrion, 2007). This is mainly due to the fact that under the European system of free allocation, periodical updates of the emission allocation basis introduce so-called 'opportunity benefits of production' (CE, 2008a).

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[1] In the case of pure grandfathering, the government puts a cap to emission space, but freely allocates the emission space to those companies who were already 'occupying' this space before the start of the system. These companies, the 'grandfathers', receive free 'grandfathered rights'. A grandfathered right gives the owner the (perpetual) right to receive *each year* one emission allowance. The grandfathered rights are fully tradable and their value or price is equal to the discounted stream of allowances, i.e. the price of a single allowance divided by the interest rate. Such grandfathered rights are comparable to land property, which either can be fully sold or be rented to others for specific periods of time. Similar grandfathered rights also exist in the case of fish catching ('fish quota'), milk production, pig farming or SO_2 trading in the United States.

In addition, current entry and exit conditions have also a reputedly distortive effect (Ahman *et al.*, 2006).[2]

The literature converges that auctioning, in the context of the EU ETS, results in lower emission prices, stabilizes price developments on the ETS market and assures that new and existing firms are treated alike. However, auctioning will result in a substantial transfer of money from business to governments. Governments are, according to economic textbook wisdom, assumed to recycle such revenues in a form of lump sum payments (without affecting other prices) into society.[3] However, strong political pressure may occur to regard these revenues as sources of income to finance other projects (for example nature development or climate adaptation projects). Such a way of dealing with the revenues from auctioning may result in welfare losses or 'governmental failures' because there is no guarantee that such projects will ensure using the financial resources in the most effective way, where the welfare of the society will be maximised. This may easily have a negative impact on future economic growth.

An additional drawback of auctioning is that prices of products manufactured in the EU will be higher as producers will pass the increase in marginal costs onto the prices. This may give EU manufacturers a competitive disadvantage on world markets resulting in a fall in exports and an increase in imports from countries outside the EU.[4] This not only is negative for the welfare levels in the EU, but also has an impact because outside the EU: emissions will rise due to climate policies within the EU. This has been labelled as 'carbon leakage'. It is nowadays common to distinguish 'investment leakage' where new investments in energy intensive production facilities takes place outside the EU and 'product leakage' where the share of EU producers in both export and internal markets diminishes. This distinction, however, remains a bit fuzzy because in the end 'investment leakage' must translate itself into 'product leakage' and vice versa.

Free allocation, on the other hand, is believed to impact less severe on 'carbon leakage'. In the revised the EU ETS Directive (2009/29/EC) free allocation is presented as the prime mechanism through which the EU wants to tackle carbon leakage. It is clear that under free allocation profits of firms are less affected, as no money needs to be spending for emissions that fall under the cap. While this may reduce the 'investment leakage', the impacts on 'product leakage' largely depend on the question if firms pass through the opportunity costs of their freely obtained allowances in the product prices. Opportunity costs are defined as foregone benefits of an alternative use of a given resource. In other words, not what something costs, but what something potentially yields determines it's price. Freely obtained allowances cost

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2 To distinguish between free allocation under the EU ETS and the pure form of grandfathering (where the allocation basis is fixed forever), we assign the term free allocation to the type of allocation that is common in the EU ETS and reserve grandfathering for the pure form of grandfathering from the literature.

3 The way the governments deal with these resources has an impact on acceptability of the tradable permits scheme and on social welfare. The revenues could be used to offset the costs to companies that are obliged to take part in the emission trading – but this will impact on the efficiency of the emission trading scheme. Alternatively, revenues can be used to correct for some distortions in the economy, e.g. in the labour market. In this way, a sort of 'double dividend' can be created, where environmental policy instrument which makes the polluters pay for emission allowances generates revenues which can be used for other governmental policies aimed at increasing the society's welfare.

4 The impacts will not only fall on producers – a deterioration of the terms of trade will have the consequence that also consumers will see their welfare reduced.

nothing, but would have yielded the opportunity costs of selling them on the ETS markets. Therefore the following conclusion can be made: free allocation has only less impact on ‘product leakage’ *if the opportunity costs of the freely obtained allowances is not passed through in the price of the products.*

summarizes all potential benefits and risks associated with allocation for the EU ETS.

Table 1 Benefits and risks of two different allocation mechanisms

	Auctioning	Free allocation
What is it?	In this case, the government holds yearly auctions for emission allowances, i.e. the allowances to emit one ton of CO_2. The government should recycle the revenues for purposes that are unrelated to the origin of the returns, for example by lowering its national debt or by *lump sum* lowering existing taxes.	In this case, the government sets a cap and allocates the available emission space each year according to a baseline. Baselines can be historical emissions or any other indicator, for example a system of benchmarks.
What are the main benefits?	1. Lower emission prices as all opportunities to reduce emissions are considered resulting in less chances for “product leakage” if companies would pass through the opportunity costs under free allocation. 2. Auctioning rewards early movers by lowering the bill from the auctions and assures that new entrants are treated similar to existing companies. 3. Auctioning gives a more direct stimulus to innovation. 4. Auctioning stabilizes eventual price shocks and prevents the EU ETS prices from becoming negative even if targets are not tight enough.	1. Easier to achieve politically because of lower costs of compliance for the companies and because no income transfers from companies to governments will occur, which makes it less vulnerable to “government failures”. 2. Less negative impacts on the profits of firms and thereby less chances on “investment leakage”. 3. If firms do not pass the costs of freely obtained allowances in the product prices, less chances on “product leakage”.
What are the main risks?	1. Large transfers of income from companies to governments will occur. The recycling of the revenues from the governments bears the risk of introducing ‘government failures’ that hamper the efficiency of the system of auctioning and have a distortive effect on the economy. 2. The profit base of business may be deteriorating resulting in “investment leakage” where EU companies prefer to invest outside the EU. 3. EU companies have to ask higher prices to cover up the costs of auctions introducing import substitution and “product leakage”. 4. Organizing the auctions can result in considerable administrative burden, not only for governments but for companies as well.	1. Companies may still charge the opportunity costs of their freely obtained allowances and obtain windfall profits. This entails large income transfers from consumers to companies. 2. If opportunity costs are passed through in the prices, “product leakage” may occur. 3. Free allocation may be perceived as unfair to “early movers”. Benchmarks to reward early movers may be cumbersome and involve large administrative costs. 4. Some studies have shown that free allocation, especially if windfall profits can be made, may act as a stimulus to attract foreign investment in energy intensive industries thereby resulting in a “pollution haven”.

As we see from this table, each system has advantages and drawbacks. In general one may conclude that auctioning has the advantage of being more efficient but runs the risk of resulting in carbon leakage. Free allocation is less efficient but may have less impact on carbon leakage. However, this critically hinges on the question whether companies pass the costs of the freely obtained allowances into the product prices. This will be elaborated in the next section.

2.3 Theory of cost-pass-through for common cost increases

Can companies pass through the costs of their freely obtained allowances? In this paragraph we will elaborate on that question from a theoretical perspective for the case that all companies are being faced with an increase in their costs. In paragraph 2.3 we will elaborate on the issue that only a part of the companies will be facing higher costs.

Costs concepts include opportunity costs

In economics, it is normal to distinguish implicit and explicit costs. A firm's explicit, tangible, costs comprise all recorded payments to the factors of production the firm uses. Wages paid to workers, rents paid on loans and money paid to suppliers of raw materials are all included among the firm's explicit costs. These costs are recorded and form the basis of the *accounting* principles in business administration.

A firm's implicit costs consist of the opportunity costs of using the firm's own resources without receiving any explicit compensation for those resources. For example, a firm that uses its own building for production purposes forgoes the income that it might receive from renting the building out. Although this building may not be recorded as an expense, it is still a cost to the firm, preventing the firm alternative usages of this building. This is called an opportunity cost. In a similar way, the freely obtained allowances in the EU ETS represent an opportunity cost to the firm. The allowances can be used to cover the emissions of an additional unit of output, but they can also be sold on the EU ETS market.

While for business administration only the recorded costs matter, most firm decisions are made taking also the opportunity costs of possessions into account.

Firm behaviour is to maximize profits

According to traditional neoclassical economics, firms aim to maximize profits. It is important here to state that the profitability over invested capital is assumed to be the prime motivation of firms, not maintaining market shares. Output is – within certain limits - flexible and the firm will produce just as much output as the profitability over its invested capital will be maximized.

The firm's primary objective in producing output is to maximize profits. The production of output, however, involves certain costs that reduce the profits a firm can make. The relationship between costs and profits is therefore critical to the firm's determination of how much output to produce. In other words: the firm adjust its output to maximize profits.

As firms aim to maximize profits, opportunity costs are being reinforced as the proper cost concept to take into account for valuing possessions. Freely obtained allowances can be either sold on the EU ETS markets or used to cover the firm's own production – whatever would yield the biggest profit. This indicates that for business decisions related to the output (e.g. expanding or shrinking production), the opportunity costs of the freely obtained allowances should be taken into account as profit maximization can only be correctly calculated by considering the alternative use of the EUAs.

Firm behaviour at the market

The extent to which the carbon allowance costs are passed through to the product prices depends largely on three factors (Sijm *et al.*, 2009): (1) the number of firms active in the market indicating the level of market concentration (i.e. if the market structure is monopolistic, duopolistic, oligopolistic or competitive), (2) the shape of the demand curve and (3) the shape of the supply curve.

The figures below illustrate a mechanism of cost-pass-through in full competition and in monopoly, assuming variable marginal costs of production (i.e. upwards sloping supply curve) and linear demand. Due to emissions trading, the supply curve shifts from S_0 to S_1 by the amount c of carbon costs (assuming the same emission factor or carbon cost per unit of production).

Figure 1 shows first the situation of a firm facing perfect competition, where prices equal marginal costs. The increase in marginal costs due to carbon costs equals f while the difference between carbon costs and marginal costs equals g = c – f. It can be seen that ETS-induced increase in competitive prices (P_0-P_1) equals the increase in marginal costs and is lower than the carbon costs of emissions trading. The less elastic the demand curve and the more elastic the supply curve, the higher the ability of pass-through of carbon costs. With a perfectly elastic supply curve (i.e. constant marginal costs), increase in price would be equal to increase in costs, equal to c. This implies that the risk of a firm falling out of the market as a result of ETS is higher with a less elastic MC (supply) curve.

Figure 1 **Pass-through of carbon costs under perfect competition, facing variable marginal costs and linear demand**

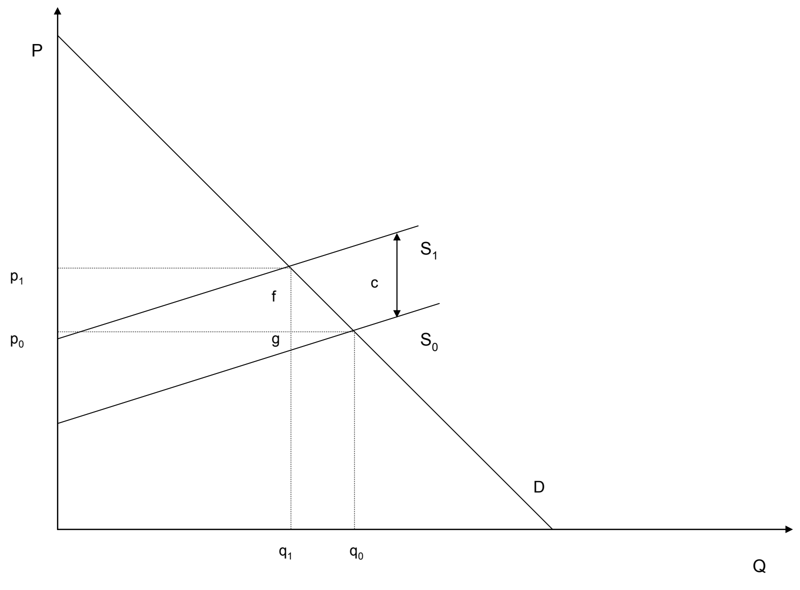
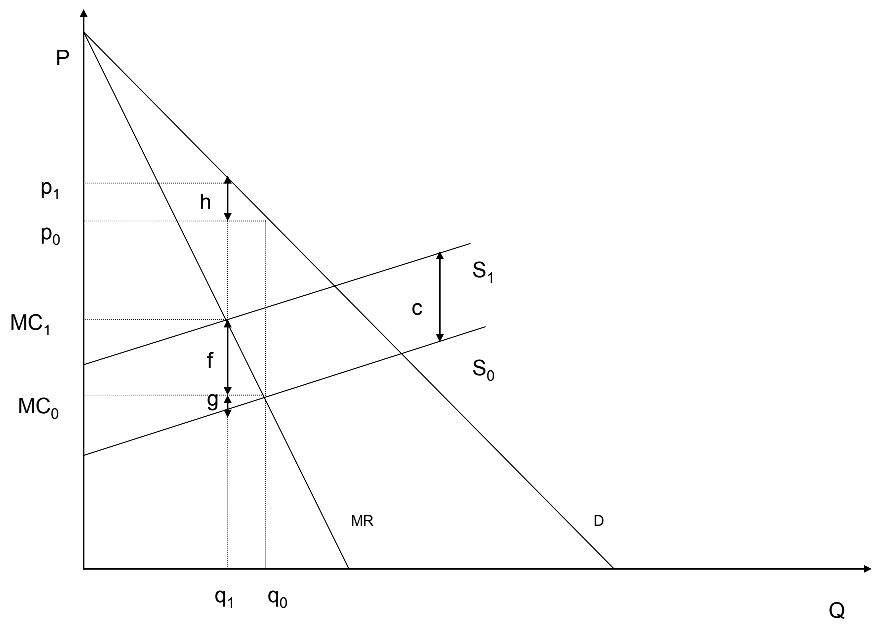


Figure 2 shows the situation of a firm in the conditions of a monopoly, where the prices are not equal to marginal costs any more. The rule that marginal return (MR) curve is twice as steep as the demand curve[5] implies that the pass-through-rate (PTR), defined as dP/dMC, is always equal 50%, regardless of the slope of the demand and supply curves. Because of simple rules of geometry, the h interval in the picture below (equal to price change) will always be two times shorter than the f interval (equal to change in MC due to ETS allowance price). How much the change in MC will reflect the ETS price still depends on elasticity of both demand and supply, in the same way as in perfect competition.

Figure 2 Pass-through of carbon costs under monopoly, with variable marginal costs and linear demand



Summarizing from the findings of Sijm *et al*. (2009) it can be said that the ability to pass through the costs depend on the elasticity of the demand and supply curves and the market structure. Sijm et al. show that with linear demand, the more competitive the industry, the greater the PTR defined as dP/dMC, which is a somewhat counterintuitive conclusion. For example with a perfectly elastic supply curve, a fully competitive firm will be able to transfer full costs of ETS on while a monopolist – only half.

5 This rule results from the definition of marginal revenue (MR) which is equal to incremental revenue resulting from increasing production by one unit. Therefore, MR can be calculated as a derivative of the function of total revenue from production, which is defined as production times price. Demand curve gives relationship between price and amount in the form p(y) = a – by, where a and b are simply regression coefficients (a being the constant term). Thus total return (TR) will have a form p * y which leads to an equation TR(y) = ay – by2, and the first derivative of this equation will have a form MR(y) = a – 2by. Therefore, the MR curve has the slope that is two times larger than the slope of the demand curve.

Moreover, also the shape of the demand and supply curves matter for the ability of passing though the costs. With iso-elastic demand[6] the situation is different, as more competitive market implies fewer possibilities for cost-pass-through. The PTR may then be substantially higher than 100% when N is small and demand is less elastic, and decreases towards 100% when markets become more competitive or demand becomes more elastic.

These conclusions are based on assumptions that companies are trying to maximize their profits, that there is no market regulation and that there are no market imperfections except for non-perfect competition. However in practice, if any of these assumptions does not hold, cost-pass-through rules may be different than stipulated.[7]

2.4 Theory of cost-pass-through for unilateral cost increases

The previous paragraph has analyzed the situation of cost-pass-through in the case of a common cost price increase. This cost price increase can be expected to be passed through into the prices, as we have shown. Moreover, not only tangible costs but also opportunity costs are to be reflected in the increase in product prices. The exact pass-through-rates were determined by the supply and demand curves as well as the market structure and can be expected to range between 50-100% for traditional demand and supply curves and above the 100% for the iso-elastic demand curves.

What happens if the marginal production costs rise for only EU countries while producers from other countries will not be faced with a cost increase? The answer depends on the fact whether the affected companies are *sheltered* from or *exposed* to competition with companies that do not participate in the EU ETS. In the case of sheltered economic sectors, the situation will not change compared to the analysis in paragraph 2.2 and a new equilibrium market price will come about where the new marginal production costs equal the marginal benefits of production.

Depending on the price elasticity of demand for the specific good, the new market price will be somewhere between the old price and the old price plus the full marginal cost increase. The profit of the companies will be somewhat lower, as demand is reduced. The marginal producer will be driven out of business, as he is unable to produce at the new price level. Profit margins for the remaining companies will hardly be affected.

In the case of *exposed* economic sectors, however, the situation is different. A sector is exposed to competitors outside the EU if the relevant market is larger than the EU. In that case, the EU market acts in dependency with other markets and distortions on the EU market will have repercussions on other

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6 Iso-elastic demand curves have constant elasticities all along the demand curve. They are often used in econometric work.

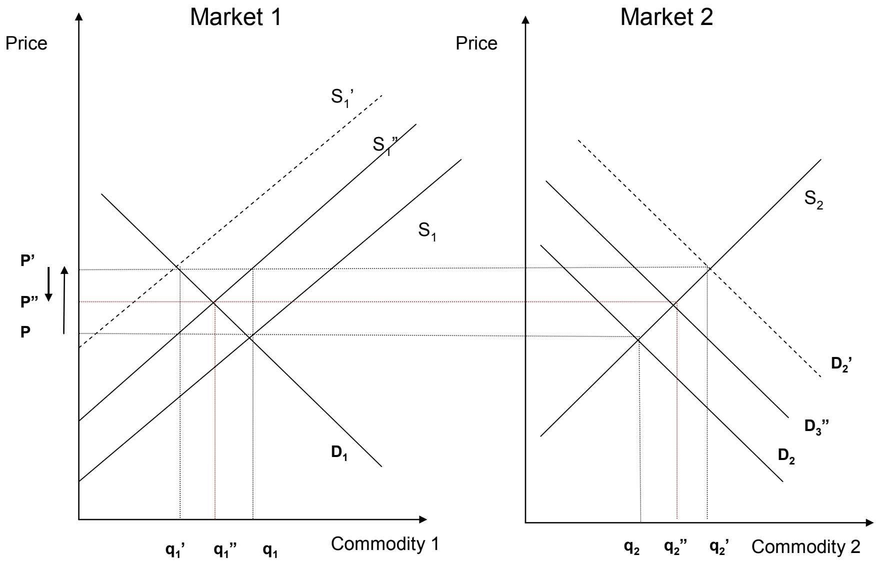
7 There are, for example, two important situations distinguished in the literature in which cases prices are not determined by marginal costs, but by *average* production costs (plus a markup to obtain profit). First, in the retail sector, where the proliferation of products implies that a careful study of demand for each product is uneconomic (Smale *et al.*, 2006). Second, in regulated markets, such as the electricity market (Kruger *et al.*, 2007) where government may demand average cost pricing to suppress monopolist profits. Lucas (2003) presents a useful survey of the various econometric and case study evidence for and against average cost pricing, and suggests that both average cost and marginal cost pricing are plausible, and that further empirical research is required before any conclusions can be drawn (Smale *et al.*, 2006).

non-EU markets as well. Prices of EU markets and foreign markets will hence be mutually dependent.

The importance of prices in defining a market was recognized already in the first half of the XIX century by Cournot, who defined a market as follows: “It is evident that an article capable of transportation must flow from the market where its value is less to the market where its value is greater, until difference in value, from one market to the other, represents no more than the cost of transportation” (Cournot, 1971). Similar definition was given by Stigler (1969), who defined a market as “the area within which the price of a commodity tends to uniformity, allowance being made for transportation costs”.

Such definitions led to a concept of the Law of One Price (LOP), which says that in an efficient market identical commodities must have the same price, Asche *et al.* (2004). Figure 3 depicts how two separate markets can integrate and conform with the LOP in the situation where the price in one market increases due to introduction of tradable emission allowances. For simplicity, prices in both markets are initially normalized at p. Assume that in Market 1 the increase in price resulting from cost-pass-through after the purchase of allowances makes the demand shrink, which consequently shifts the supply curve from S1 to S1’ and the price increases to p’. Now there is a price differential between Market 1 and Market 2 which makes it profitable to export part of Market 2 to Market 1. Hence, the good will be exported to Market 1 and the increased demand at the Market 2 will cause the price at the Market 2 to rise and the price at Market 1 to fall. If the whole amount of import from the Market 2 could be sold at the Market 1 against the price P’, the price would stay at this level at both markets and the amount of import at the Market 1 would amount to q1 – q1’ and would be equal to the amount of export q2’ - q2. However the increased supply at the Market 1 will have an effect of lowering the price at the Market 2, which will result in gradual adjustment to reach a new balance in both markets, at P”, where the amount of import from the Market 2 equals q1” – q1’ and is equal to export from the Market 2 in the amount of q2”- q2. Increased demand will induce price increase in Market 2 to the point where prices at both markets are equal (= p’).

Figure 3 Integration of two markets with goods that are perfect substitutes



Source: Based on Asche *et al.* (2004).

This example shows that price increases in one market, for example due to the EU ETS, will have the result that prices may increase in other markets as well. Hence, even if all of the EU ETS costs will initially be passed through in the product prices, the total price increase will be less as the result of the lowering impact on prices from imports from other countries. It is important to notice that this result holds irrespective to the question whether the rights will be auctioned or freely distributed because as discussed in previous sections, the firms have a tendency to pass at least partly the opportunity costs also in case of receiving allowances for free.

If markets are perfectly integrated, there will be one price internationally allowing for eventual transportation costs. However, as indicated by Armington (1969), this will rarely be the case. Products produced in different countries are often imperfect substitutes due to product differentiation and transportation costs. The so-called Armington elasticity represents the elasticity of substitution between products of different countries. If both commodities are perfect substitutes (perfect market integration), the situation looks like in Figure 3 above where the price increase in Market 1 is giving an equivalent response in Market 2. If the two commodities do not compete, there will be no influence of prices in Market 1 on prices in Market 2 (no integration).

In many cases the situation will lie in between these two extremes.
The literature devoted to price transmission indicates that there are at least six groups of factors affecting market integration (based on Conforti, 2004):

1. Transport and transaction costs. Transport costs are often assumed to be constant over time however it does not have to be the case thus they can also be modelled. Regarding transaction costs, these can be classified into three groups: information, negotiation, and monitoring and enforcement costs.
2. Market power. The mechanism of price transfer described above refers to a perfectly competitive market. However the market can be organised differently, e.g. there may be an oligopoly structure with price leaders and followers, and then the price transfer mechanism would be different. It

may also be the case that e.g. input price increased in an industry might be passed over to consumers while input price decreases can be captured in the mark-ups of the industry.

3. Increasing returns to scale. Increasing returns to scale in production can be the cause of a market power, however their effect on price transmission may be different from that on market power.
4. Product homogeneity and differentiation. The degree of substitutability affects the process of price transmission. According to so-called Armington assumption, goods produced in different countries are not perfectly substitutable.
5. Exchange rates. Changes in the exchange rates cannot always be easily passed through on output prices. Costs related to exchange rates fluctuations can be viewed as a type of transaction costs, with an element of uncertainty.
6. Border and domestic policies. Trade policies such as import tariffs and quota affect spatial price transmission directly but also domestic policies affecting price formation such as taxes and subsidies may have influence on the process of market integration.

These influences may imply that a larger or a smaller part of the costs than depicted in Figure 3 may be passed through on the EU markets. If the EU market is integrated with other markets for the same commodity, price increases on the EU market will to a certain extent stimulate imports and thereby increase prices in the other markets, but the EU market may not be flooded with imports from other countries as these products may be imperfect substitutes for EU products. In Chapter 3 we will present an econometric approach towards assessing whether markets are integrated or not.

2.5 Empirical observations and Porter hypothesis

According to conventional wisdom, environmental regulations impose significant costs, which may slow productivity growth. If a given country imposes unilaterally environmental protection regulations, this may hinder the ability of firms from this country to compete in international markets. This loss of competitiveness may be reflected in declining exports, increasing imports, and long-term movement of manufacturing capacity to countries with less stringent environmental regulations. The last phenomenon may lead to creation of so-called pollution havens and is believed to be particularly strong for pollution-intensive industries.

It should be noted that the general tendency that environmental regulations impose additional costs on industry has at the beginning of the 1990s been questioned by Michael E. Porter (Porter, 1991). Porter in his famous hypothesis stated that environmental regulations could actually have a positive impact on competitiveness. The main mechanism indicated by Porter is that environmental regulations induce innovations that are in the end lowering production costs and/or increasing attractiveness of products. In his paper, Porter described a few cases of firms where such a mechanism has been effective. This hypothesis, however, has not been proved to work as a general rule (see e.g. Brannlund and Lundgren, 2009). Although some cost efficiencies can be measured (especially in the costs of meeting environmental standards), the total benefits from innovation do not seem to outweigh the costs of more stringent environmental standards for most industries.

However, the main question is then subsequently whether the higher costs for industries in countries that unilaterally impose environmental policies, do impact on the international competitiveness of companies? The hypothesis that environmental regulations have an impact on international trade flows has been tested in several research studies. This literature focussed primarily on the relationship between environmentally motivated costs for companies and their export position. Jaffe *et al.* (1995) provide a survey of papers focusing on changes in international trade competitiveness of the United States as a result of imposition of relatively stringent environmental regulations in the 1970s. For example Kalt (1988) regressed changes in net exports of 78 industrial categories against environmental costs and other relevant variables during the period 1967-1977 and found a statistically insignificant inverse relationship. When the sample was restricted to manufacturing industries, however, the predicted negative effect of compliance costs on net exports became significant. In another survey, Tobey (1990) found that in five pollution-intensive industries – mining, paper, chemicals, steel, and metals – environmental stringency was not statistically significant determinant of net exports. These results are consistent with the results of some other studies reported in Jaffe *et al.* (1995).

The same paper searches for evidence of creation of pollution havens in countries with relatively lax environmental regulations (with the assumption that most developing countries have less stringent environmental regulations than developed countries). For example, Low and Yeats (1992) examined shifts in world trade patterns in the period 1965-1988 and reported that developing countries gained a comparative advantage in pollution-intensive products at a greater rate than developed countries. They have also noted, however, that industrialized countries accounted for the lion's share of the World's exports of pollution-intensive goods in the period under examination, contradicting the notion that pollution-intensive industries have fled to developing countries. Secondly, even if some pollution-intensive industries have moved to developing countries, this may be simply due to increased demand for products of these industries in industrializing countries. Another factor explaining this phenomenon may be natural resource endowment – as for some industries it is economically justified to be located close to the natural resources needed for production.

Robison (1988) examined US trade patterns in the years 1973-1982 in iron and steel industry and concluded that the US imports of relatively pollution-intensive goods have increased during this period but overall, the impact of increased abatement costs on the US trade is small.

Another dimension of the likely impact of environmental regulations on competitiveness is a potential trend in direct investment, creating so-called capital flight to locations with less stringent regulations. Several studies reported in Jaffe *et al.* (1995) suggest that stringency of environmental regulation has little or no effect on location of new industrial plants. Bouman (1998) tested the hypothesis that environmental costs induce capital flight on extensive data sets from Germany and the US. He found a small effect of environmental abatement costs on direct foreign investment; clearer in case of the US where almost for all sectors a positive coefficient was found (i.e. higher environmental costs for a given industry are related with higher direct foreign investment). In case of Germany this effect was less clear, and in some sectors (mostly highly concentrated sectors, with small number of firms) the coefficient was even negative. This last phenomenon was explained with a hypothesis that in case of highly concentrated industries the coefficient reflecting abatement costs was related to the situation after the evasion induced by environmental regulations took place. In an extreme case of one firm producing the whole output of an industry, if environmental regulations are tightened, the firm will stay in the country if increase of costs of environmental compliance is relatively small and will relocate the whole production if increase is significant. In such case, the coefficient related to environmental costs is inversely related to the coefficient related to direct foreign investment.

Van Beers and van den Bergh (1997) and Harris *et al.* (2002) tested the hypothesis of impact of environmental stringency on trade flows on a set of OECD countries. They constructed an index of environmental stringency based mainly on energy intensities and recycling rates. The results of this study showed that especially exports are negatively and significantly affected by more stringent regulations but do not find negative significant results for the imports. Some other studies, however, do find a significant effect of costs of environmental regulations on net imports. Jug and Mirza (2005) give a few examples of such studies, which used data from different states of the US. For example, Ederington and Minier (2003) and Levinson and Taylor (2004) found a high positive effect of the US abatement costs on US imports. They also pointed out that environmental regulations and trade are endogenous to each other.

Jug and Mirza show that the fact that in international studies the impact of environmental regulations was found to be weak or insignificant was related to measurement errors and the estimation of the wrong model (endogeneity arising due to pooling of countries or industries). After controlling for these biases, the authors obtained a significant elasticity of import demand to the stringency of regulation. The authors used European abatement costs data as a measure of environmental stringency. They found that environmental stringency matters more for Eastern European exporters, since EU importers might be more sensitive to the perceived lower quality of products and lack of variety in relation to this region.

Jug and Mirza point out in conclusions that the effect measured as elasticity of imports to stringency of environmental regulations is a pure cost effect. However there might be many other positive effects on trade that are related to more stringent environmental regulations, such as increase in perceived quality by the consumer or investment in new low pollution technologies by producers – these two factors that could be favourable both to trade and welfare.

Summing up, literature on impact of environmental regulations on trade flows and on location of direct investment is not entirely conclusive. However recent literature indicates that with appropriate model specification a significant effect in international trade can be found, so that imports from countries with less stringent environmental regulations tend to be higher than imports from countries with relatively tighter regulations. The hypothesis of capital flight and creating pollution havens has so far not been proved on international scale.

2.6 Conclusions

Two possible forms of allocation in the EU ETS are auctioning and free allocation. Auctioning is in general more economically efficient but bears the risk of carbon leakage and problems of introducing governmental failures in recycling auction revenues. Free allocation implies that the explicit costs of complying with the EU ETS for the companies are much lower than under an auctioning regime. These lower costs for companies can be beneficial for political acceptance and reduce the risk of carbon leakage (mainly through investments). However, free allocation runs the risk of introducing inefficiencies in the system and introducing windfall profits in sectors that do pass through the opportunity costs of their freely obtained allowances.

Within the EU ETS, sectors prone to carbon leakage receive rights for free. However, free allocation is only an appropriate mechanism to combat carbon leakage if companies in exposed sectors do not pass through the costs of their freely obtained allowances into the product prices. This can be questioned from a theoretical perspective. Within the framework of neoclassical economic theory, firms are supposed to maximize profits and prefer profitability to maintaining market shares. Profits are maximized when the firms take into account the opportunity costs of their freely obtained allowances in setting their product prices. How much the firms will be able to pass the costs on depends on market structure and on elasticity of demand and supply. Theoretical analysis shows that firms will be able to pass through 50% of the costs under the monopoly, and 0-100% of the costs, depending on the elasticity of supply and demand, under perfect competition. Assuming non-linear demand and supply curves would imply that sectors even pass through more than 100% of the opportunity costs.
The extent to which the prices for a given good will rise depends also on the degree of international market integration. If markets for specific goods extend over country borders, and if the products produced in different countries can be regarded as almost perfect substitutes, the mechanism of the law of one price will induce increase in imports from the countries without carbon pricing to the country where the firms have to comply with the trading scheme. This mechanism will have a lowering impact on the price level of the country with obligatory carbon pricing, while the price abroad will increase due to increased demand. The extensive empirical literature indeed found some evidence for this type of import substitution. However, the effect is small. There has been no proof in the literature that this would distract capital to be invested in countries with less stringent environmental regulations.

Environmental regulations such as the EU ETS may also imply positive effects for competitiveness of companies and even countries, which is stipulated in the so-called Porter hypothesis. The main mechanism indicated by Porter is that environmental regulations induce innovations that are in the end lowering production costs and/or increasing attractiveness of products. While many examples of firms which benefited from environmental regulations that gave them impulse for more cost-effective production can be found in literature, generally the benefits from innovation do not seem to outweigh the costs of more stringent environmental standards for most industries.

3 Empirical estimation procedure

3.1 Introduction

This chapter will set out the empirical estimation method to be used in this research to determine the question whether companies have passed through the costs of their freely obtained allowances into the product prices. First, in paragraph 3.2 a general description will be given of the possible estimation methods. Then, in paragraph 3.3 a model will be developed that aims to estimate the extent of cost-pass-through. Subsequently, in paragraph 3.4 we describe the estimation procedure applied in the quantitative research. Paragraph 3.5 describes the data and conducts unit root tests on these data to test them for stationary. This chapter does not contain estimation results; these are presented in Chapters 4, 5 and 6.

3.2 Empirical estimation method

The question whether EU producers have passed through the CO_2 costs in the product prices will be elaborated in this research with the use of econometrics. Econometrics is the science that combines economic theory with statistics to analyze and test economic relationships. Although many econometric methods represent applications of standard statistical models, there are some special features of economic data that distinguish econometrics from other branches of statistics. Economic data are generally observational, rather than being derived from controlled experiments. Moreover, the observed data tend to reflect complex economic equilibrium conditions where individual influences cannot be singled out. Consequently, the field of econometrics has developed methods for identification and estimation of simultaneous equation models. These methods allow researchers to draw conclusions on the nature of the economic processes they tend to observe.

Sijm *et al*. (2005, 2006 and 2008) were the first to use econometrics to analyze the influence of freely obtained EUAs on the price of power suppliers. They examined whether the daily fluctuations in the spot prices on CO_2 markets have been forwarded into the prices of electricity, taking into account the costs of fuel inputs. Their research was influential as this was the first study to show that the opportunity costs of freely obtained allowances might have been passed through in the product prices. However, applying this method to other sectors is not feasible. Whereas the price of electricity is largely determined by the price of inputs of fossil fuels, prices for other products are determined by a multitude of inputs. Collecting cost information on each input would simply be too time-consuming.

To work around this problem a different approach is chosen here. This approach is based on the theory of market integration assuming that prices of inputs and outputs of energy intensive products are linked globally. If, for example, the price of steel increases in the United States, this will also have repercussions for the price of steel in e.g. the EU. Through trade flows the markets of steel are to a certain extent interlinked with each other. The same hold true for the market of inputs in the steel making process. Prices of iron ore are most likely being interlinked through trade flows. If the price of iron ore rises for EU producers, this will most likely translate itself through a rise of iron ore prices for US producers. In this system of market dependencies it can be investigated if the price of CO_2 allowances is significantly influencing the steel prices in the EU. If the price of CO_2 allowances would drive up EU prices of steel, this would be a sign that the costs of freely obtained allowances have been passed through in the product prices.

Econometrically, this boils down in the theory of co-integration for which Engle and Granger (1987) have received the Noble prize laureate in 2003. Their econometric method can be regarded as the statistical equivalent of the economic theory of market integration. As we saw in Chapter 2, markets influence each other through a complex web of economic relationships. The law of one price states that integrated markets contain one price allowing for differences in transport costs and other factors. The statistical theory of co-integration explicitly tests whether markets are co-integrated by investigating the stochastic patterns in the price developments in both markets. If the price developments contain the same stochastic pattern, so that their common development can be considered as stationary, we say that these markets are co-integrated.[8] Co-integration analysis investigates as a test whether two markets are interconnected so that price shocks in one market lead to adjustments in both markets. We say that two markets are linked (co-integrated) if a market equilibrium exists so that a price hike in one market leads to changes in other markets so that long-term balance between the two markets is maintained.

The EU ETS can act as one of the mechanisms through which the long-term balance between two markets, e.g. the markets in the EU and the USA, is influenced. Since 2005, an emissions trading system was introduced in the EU market. If companies did pass through the costs of their freely obtained allowances, this would have pushed the EU prices higher compared to the USA prices. If the US and EU markets would be integrated, these higher prices may have resulted in price responses in the US market such as a reduction in imports from the EU or more exports to the EU. The consequence of these responses can be that the price in the US market is going to be higher and that the EU price is going to fall so that the full opportunity costs are no longer to be fully reflected in the price.

3.3 Model formulation

The general form of the model that we aim to estimate explains the development in EU prices in terms of prices of prices of the same product in non-EU markets, CO_2 prices at the EU ETS market and other factors, such as exchange rates. The model to estimate could hence look like:

$$P_t(EU) = \alpha + \beta_1 P_t(non-EU) + \beta 2 P_t(CO2) + \beta 3(\in_t / \$_t) + \varepsilon_t \qquad (1)$$

Co-integration analysis implies that in this system some kind of equilibrium relationship is to be found. This equilibrium relationship contains the endogenous variables of the estimation. A variable from (1) is endogenous if it can be moved to the left hand side in equation (1) while maintaining an economic meaning. Quick inspection learns that from the variables in (1), most likely only the prices in the EU and non-EU markets can be considered as

8 Co-integration has more than one meaning in economics. One interpretation of co-integration is that they share common stochastic trends (Stock and Watson, 1988). A price increase in iron ores, will, for example, influence both prices of steel in the US and the EU. Hence, these prices tend to be influenced by the same stochastic trends.

endogenous as the other variables (CO_2 prices and exchange rates) are most likely not being influenced by the price developments at product markets.

In its most simple form, this implies that the equilibrium relationship between the EU and, e.g., the US market can be described as the combination of two equations:

$$P_{EU} = \alpha_i + \beta_i P_{US}$$
$$P_{US} = \alpha_j + \beta_j P_{EU} \qquad (2)$$

In this long-run relationship the coefficients *α*'s and *β*'s capture the long-term differences between the EU and the US market due to factors as transport costs, etc. Introduction of the EU ETS in this system will make EU prices increase (if EU producers would pass through the costs of their freely obtained allowances), resulting in price adaptations in the US markets as well. The total possibilities to pass through the costs, will in the end determine on the coefficients α and β after introduction of the EU ETS and on the extent and speed of adjustment towards the market equilibrium.

The model where both the short- and long-run dynamics are included looks formally like this:[9]

$$\Delta P_{t,EU} = \beta_t \Delta P_{t,US} - (1-\phi_{EU,US})(P_{t-1,EU} - \lambda P_{t-1,US} - \delta) + \alpha_t \Delta P_{co2,t} + \sum_{i=1}^{m} \sum_{j=1}^{n} \gamma_{t-j,i} Z_{t-j,i} + \varepsilon_t \quad (3)$$

The price changes in EU products (on the left hand side of this equation) are here described as the resultant of three effects:

1. The price changes in the US market (coefficients β_t where the subscript t stands for the lagged responses). These coefficients will have in general a positive sign: higher prices on foreign markets will be translated to higher prices on the EU markets as well.
2. The long-term equilibrium relationship between EU and US products ($P_{t-1,EU} = \delta + \lambda P_{t-1,US}$) where the coefficient $(1-\phi)$ indicates the speed of adjustment to the long-run equilibrium. The coefficients of adjustment are most likely negative on the EU markets (indicating that an unexpected price hike due to e.g. a strike in Europe will result in a downward adjustment in later periods due to increase imports). For the US market the coefficients of adjustment are expected to be positive.
3. The exogenous influence of CO_2 prices, given by $\alpha_t \Delta P_{co2,t}$. If the coefficients for a_t are significantly larger than zero, this is a sign that prices on the EU markets tend to increase due to the EU ETS. The price of CO_2 can be significant with a certain lag as in some cases there is a lag between the period that the product is produced and its price is recorded in the statistics.
4. A set of Z_i exogenous variables that have an external influence on the European price with a certain lag. These external variables are included here to control the estimates. We used here the exchange rate, the price of crude oils and the Dow Jones and AEX index for developments on the stock exchange markets.

[9] A similar equation can be depicted for the US market (but not given here).

It is important to realize that in the theory of market integration not only adjustments can be expected on the EU markets, but also that these adjustments tend to spread to non-EU markets as well. Higher prices on the EU market due to the EU ETS may induce imports that result in higher prices on other markets as well. Such price adjustments, both in the EU and foreign markets can be very small (in the order of less than one tenth percent) and not visible to the naked eye. By using econometric techniques, however, the influence of this one parameter (CO_2 prices) on the total stochastic influences on the price levels can still be singled out. Estimation methods and significance thresholds have been established that consistently can determine whether the price of EUAs has had influence on the prices sold at EU markets and thereby whether EU producers were able to pass through (part of) the costs of EUAs into the product prices.

3.4 Estimation procedure

The preferred econometric model used in this study investigates whether there exists a long-run equilibrium between prices in the EU and non-EU markets. Furthermore there exists a short-term relation that explains the behaviour within a market, influenced by shocks in explanatory series, and behaviour between markets when prices are shocked out of the long-term equilibrium. This relation is estimated by a so-called 'Vector Error Correction Model (VECM)'.

A Vector Error Correction Model estimates both the long run and short-run dynamics of the markets in a simultaneous equation. The long-run equations are given by equation (2) in paragraph 3.3. The variables in the long-run equation (i.e. EU and non-EU prices) need to be co-integrated. This can be tested by Johansen Trace and Maximum Eigenvalue tests. If they are co-integrated, a VECM is the proper model to be estimated.

If the condition of co-integration is not met, then the Vector Error Correction Model cannot be used. Depending on the relation between the EU and non-EU markets other models come in sight. First, it is being tested whether the long-run equation would hold if CO_2 prices are included in the long-run relationship as an endogenous variable. In other words, we would investigate whether inclusion of CO_2 prices in the model as an endogenous variable would yield a stable long-term equilibrium between EU and non-EU prices so that the error correction model can be estimated with some adjustments.[10]

However, if the condition of co-integration is still not met, other methods must be used to obtain stationary residuals. If the EU prices or one or more of its lags cause non-EU prices and vice versa, then the variables are Granger-caused and a so-called Vector Autoregressive Model is preferred. If there exists only a one-way or no Granger-causal relationship between EU and non-EU prices, a single regression (Ordinary Least Squares) on the first differences will be executed.

The procedure, under the assumption of existence of unit roots where needed, is described in Figure 4.

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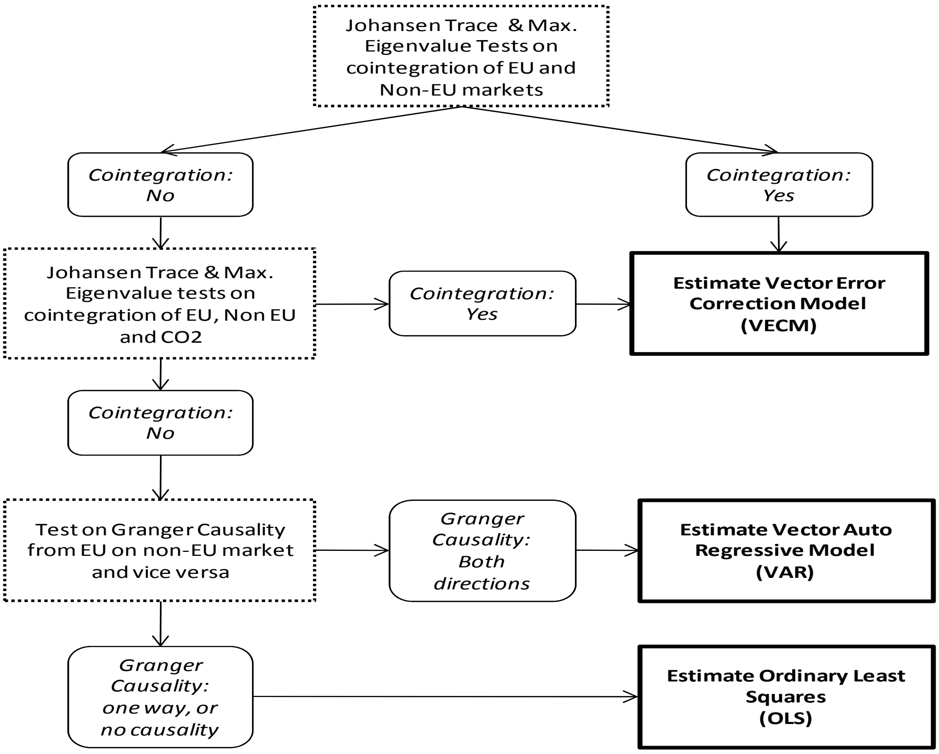
10 We prefer here the case where CO_2 prices are exogenous to the price levels in the product markets above the case where CO_2 prices are regarded as endogenous, because there is not a real economic theory that could explain why e.g. steel prices influence CO_2 prices. Therefore we first estimate the model with CO_2 not included in the co-integrating relationship.

Figure 4 **Estimation procedure in this research**



In this procedure the Johansen trace tests and Granger Causality tests are thus used to frame the model selection. The tests and models will involve several lags of each variable to arrive at the most parsimonious model. We have used the procedure as outlined in Box 1 for selecting the most parsimonious model with respect to lag length and model estimation.

Box 1 **Optimal lag and variable selection**

A parsimonious model is usually a better model in econometrics as this increases the degree of freedoms and makes the estimates more efficient. In practice this boils down to finding the right lag-length and variables to be included in the estimates. We used here the Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (SBC) as guiding indicators. Both criteria are a measure of the goodness of fit of an estimated statistical model. They are grounded in the concept of entropy, offering a relative measure of the information lost when a given model is used to describe reality. These criteria describe the trade-off between bias and variance in model construction, or loosely speaking that of precision and complexity of the model.

For the optimal lag-length in co integration tests, the SBC was used. For finding the optimal lag-length in regression estimates the AIC was used. The VECMs models have been estimated using the following procedures. Firs the optimal lag-length was found for the co-integrated variables. We investigated up to 6 lag-lengths for these variables. Subsequently first the influence of CO_2 prices has been estimated (up to 13 lags) and in later rounds lagged other control variables have been added (such as exchange rates and stock exchange indices, also up to 13 lags).

The optimal model is finally checked on higher order auto correlation using the Portmanteau Q-test statistics. If higher serial order autocorrelation could not be rejected using the 10% confidence level, the procedure is re-estimated using different lag-lengths until no higher order serial autocorrelation is plaguing the estimation model.

The whole estimation procedure hence consists of model selection, variable selection and lag-length selection using various tests and indicators. Before we can start this estimation procedure, we first have to describe the data that we will use and pretest all variables on having unit roots.[11]

3.5 Data selection and unit root tests

This estimation procedure developed above aims to investigate the relationship between the price developments in an EU and a relevant non-EU market to investigate whether the costs of freely obtained allowances have been passed through during Phase 1 and Phase 2 of the EU ETS. In order to do this, some decisions have to be made with respect to the sectors, products and markets that ought to be included in the estimations.

3.5.1 Sectors

The data collection was started for sectors representing a considerable share in total EU ETS emissions. First we selected aluminium, iron and steel, cement, refineries and petrochemicals. The method employed in this research requires that markets are somehow regionally separated but interlinked through trade flows. This appears to be the case for e.g. the iron and steel, cement, refineries and (petro-) chemicals sectors. Aluminium, on the other hand, is not clearly enough separated regionally as transport costs to the value of aluminium are very low. For aluminium, and other metals as well, there exists, therefore, more or less a global price at the London Metal Exchange which would not make it possible to estimate model (3) from paragraph 3.3.

Another problem occurred with cement price data. In order to be able to have enough observations over time, price data need to be established on a daily, weekly or monthly basis. Yearly data clearly form not a possibility here, as this would yield only 4 data points (2005-2008). Daily or weekly data are to be preferred yielding over 200 observations. However, monthly data would still give over 50 observations - small but not prohibitive small for econometric analysis. Finding such data for cement proved, however, to be impossible. Although cement is clearly a regionally differentiated market and some quantitative work suggested that the cement sector was able to pass through the costs of freely obtained allowances (Ponssard & Walker, 2008), it proved not to be possible to find price data for cement that could be used in this research (see Annex A.2 for a detailed analysis). Therefore, the analysis in this research is limited to the iron and steel, refineries and chemical sectors only.

3.5.2 Products

To investigate the relationship between EU and non-EU prices in relation to the price of EUAs, price information need to be obtained for the EU and non-EU markets for a number of products from the chemical, iron and steel and refineries sectors. The number of traded products in these sectors is huge. In order to satisfy time and financial constraints in this project, we selected for each sector a number of key products that were more or less considered to be representative for the general market situation in the sector.

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[11] All explanatory variables in the VECM need to be stationary. If the variables contain only one unit root, they are stationairy in first differences and the first differences can be included in the VECM estimation as explanatory variables.

The following products were taken into account:

Chemicals:	Polyethylene (PE), polystyrene (PS), polyvinylchloride (PVC).
Iron and Steel:	Hot rolled coil (HRC), cold rolled coil (CRC).
Refineries:	Gasoline, diesel, kerosene, gasoil.[12]

All data we use are weekly data, except for iron and steel where monthly data have been used.[13]

3.5.3 Markets

The econometric estimation model investigates the relation between the EU and a relevant non-EU market. In principle, sophisticated structural equation models could be used to deliver the relationship between the EU and all non-EU markets where the interrelationships between a set of markets (e.g. 4-10) is estimated. However, these models are often difficult to interpret and require considerable estimation efforts – especially as the data gathering process is not uniform between the various markets so that a sophisticated set of fixed and random effects must be estimated for this pool of data. Such a research project would, however, overstretch the current research project.

In this research the more simple approach is chosen where the relationship between the EU prices is compared to one other market. This other market must have trade relations with the EU market so that the sophisticated process of adjustment to price increases can be analyzed. In addition, it is essential that in this other market no form of carbon pricing takes place. Given the data availability, it became clear that the United States would most perfectly fit in these conditions. During the period that the EU ETS was in place, the Bush administration had blocked any attempt to arrive at a climate change policy so US companies were virtually free from any carbon costs.

For products from the chemical industries, we have in addition investigated the relationship between EU and the Asian markets. For gasoil, only a comparison between prices at the ports of Rotterdam and Singapore was possible – so this includes a comparison with price levels in Asia as well.

3.5.4 Time period

Data collection in this research took place in October 2009. We have collected all data up to the first week of September in 2009. Newer data after this period have not been included. Starting point for the data has been the first week of 2001 for all series, except for chemicals where we due to budget limitations have collected data from the first week of 2005. As CO_2 emission allowances were only starting to be traded on organized exchanges in the second quarter of 2005, price data of CO_2 were of course limited to this period.

3.5.5 Summary table

Table 2 gives more detailed information on the price data that have been used in this research. As can be seen from Table 2, the series under investigation include daily, weekly and monthly data. The daily data were transformed into weekly data to be included in the estimation of the weekly series, and to monthly data to be included in the estimation of the monthly series.
In Annex A.2, descriptive statistical information is given for each of the series that finally have been included in the estimations.

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[12] For kerosene and gasoil, the weekly data have been obtained from unweighted daily closing prices.

[13] The data vendor steelbb.com claims to publish weekly prices but prior to 2009 these prices simply reflect monthly prices. Therefore only monthly data have been taken into account.

Table 2 **Overview of data series used in this research (see Annex A.1 for more precise data description)**

	EU market	Non-EU market	Start (D-M-Y)	End (D-M-Y)	Frequency
Chemicals (spot prices, FOB and FD)*					
Polystyrene (PS)	EU ($/t)	US ($/t), Asia ($/t)	3-1-2005	3-9-2009	Week (average (Fr-Th))
Polyethylene (PE)	EU ($/t)	US ($/t), Asia ($/t)	3-1-2005	3-9-2009	Week (average (Fr-Th))
Polyvinylchloride (PVC)	EU ($/t)	US ($/t)	3-1-2005	3-9-2009	Week (average (Fr-Th))
Steel					
Steel hot rolled (HRC)	EU (€/t)	US ($/t)	1-2001	9-2009	Month
Steel cold rolled (CRC)	EU (€/t)	US ($/t)	1-2001	9-2009	Month
Refineries (retail prices excl. taxes)					
Gasoline	DE, FR, UK ($/gallon)	US ($/gallon)	2-1-2001	11-9-2009	Week (Monday opening)
Diesel	DE, FR, UK ($/gallon)	US ($/gallon)	2-1-2001	11-9-2009	Week (Monday opening)
Gasoil	Rotterdam ($/gallon)	Singapore ($/gallon)			
Carbon Dioxide (Spot prices and futures)					
BNS EUA 05-07 Spot	EU (€/t)		24-6-2005	25-2-2008	Daily (closing prices)
BNS EUA 08-12 Spot	EU (€/t)		26-2-2008	11-9-2009	Daily (closing prices)
Control Variables					
Stock exchange	AEX (index)	Dow Jones (index)	2-1-2001	11-9-2009	Daily (average)
Currency	Euro/Dollar	Euro/Dollar	2-1-2001	11-9-2009	Daily

Note: * Free delivery (FD) is the price inclusive of transport up to the door, usually for within the continent. Free on board (FOB) is usually the export price exclusive of transport.

3.5.6 Unit root tests on the variables

All variables need to be tested on unit roots. If two variables are included in the long-term equilibrium, both variables ideally need to have to be integrated of the same order.[14] If they are included in the short-term relation, the level of integration has to be known in order to know if these variables must be included in levels (no unit root), first differences (one unit root), or other forms (two or more unit roots). Most economic time-series contain one unit root.

Table 3 presents the t-tests and probability values for the null-hypothesis: no unit root. It also displays if it will be included in a long run or a short-run relation.

14 If the variables are not of the same order, there exists still a possible co-integrating relationship between a linear combination of these variables and another variable.

Table 3 Unit root test on the variables for this research

	T-value	Probability	Unit Root yes/no
Chemicals			
Polystyrene EU	-0.537	0.484	yes
Polystyrene Asia	-0.403	0.538	yes
Polyethylene EU	-0.330	0.566	yes
Polyethylene US	-0.578	0.466	yes
Polyethylene Asia	-0.185	0.619	yes
Polyvinylchloride EU	0.438	0.808	yes
Polyvinylchloride US	-0.684	0.420	yes
Steel			
Steel hot rolled EU	-0.333	0.563	yes
Steel hot rolled US	-0.804	0.365	yes
Steel cold rolled EU	-0.275	0.585	yes
Steel cold rolled US	-0.853	0.344	yes
Refineries			
Gasoline EU (Germany)	-0.077	0.657	yes
Gasoline US	-0.678	0.423	yes
Diesel EU (Germany)	-0.114	0.644	yes
Diesel US	-0.458	0.517	yes
Brent (control)	-0.354	0.557	yes
WTI Cushing (control)	-0.411	0.535	yes
Gasoil Singapore	-0.372	0.549	yes
Gasoil Rotterdam	-0.168	0.624	yes
Carbon Dioxide			
CO_2 prices week	-1.603	0.103	yes
CO_2 prices month	-1.367	0.157	yes
Control Variables			
AEX week	-0.552	0.477	yes
AEX month	-1.404	0.148	yes
Dow Jones week	-0.488	0.504	Yes
Dow Jones month	-0.487	0.503	yes
Exchange rate week	-1.617	0.100	yes
Exchange rate month	-1.513	0.122	yes

The conclusion is that all variables contain a unit root. This has the implication that the Vector Error Correction Model can be used without further adjustments. Moreover, all variables in the short-run relation (including all exogenous variables) have to be included in first differences to make them stationary.

4 Results: iron and steel

4.1 Market and product outline

The production of steel (and iron) is one of the most energy intensive production processes and accounts for an estimated 5.2% of total global greenhouse gas emissions (OECD, 2005). Most of these emissions come from primary steelmaking using mostly the basic oxygen furnace (BOF) process. Secondary steel making from scrap, generally involving electric arc furnaces (EAF), is about 4.5 times less emission intensive than the BOF process.

Global steel production amounted to 900 million tonnes in 2002, of which approximately 2/3 was produced via the Blast Furnace (BF) and associated Basic Oxygen Furnace (BOF) route and about 1/3 from scrap recycling in Electric Arc Furnaces (EAF). The EU is the second largest producer worldwide (after China), producing about 200 million tonnes in 2008. Steel is a heavily traded good; about 40% of worldwide production is being traded. The EU, while being traditionally a net-exporter of steel products, has over the last years become a net-importer of steel products.

Steel is not a homogenous product. There are variations in steel grades and qualities to satisfy a wide range of applications, including construction, automotive, packaging and manufacturing industries. In a way it is believed that these differences constitute a barrier to the hardship of the global market. This especially holds for flat products demanded by the automotive industry. In the EU, products and production methods are generally advanced compared to other regions (Hatch Beddows, 2007), but this advantage may vanish in the medium-term as technology spreads quickly (Hatch Beddows, 2007).

According to some (see e.g. NERI *et al.*, 2007b), the EU market can be considered as an oligopoly, meaning that producers are price makers to a certain extent[15]. This is supported by the fact that steel industries in Europe have undergone considerable consolidation over the past decades. The top five producers hold 53% of the EU market, with the transregional steel company ArcelorMittal as market leader (McKinsey, 2006). In addition, new producers face high entry barriers, since the industry is capital intensive and market entrance requires specific investments (IEA, 2005a; McKinsey, 2006).

15 The publicly announced price increase in 2008 by ArcelorMittal underscores the view that certain price setting is possible. Steel suppliers seem able to pass higher energy and ground prices on to customers, especially in the US where supply is limited (Financiële Telegraaf, 2007). It has also been mentioned that European steel prices could be intentionally influenced by, for example, temporary shut-down of units in Europe (Hindustan Times 2006 in NERI et al., 2007b).

4.2 Empirical analysis

4.2.1 Price data

A few institutes gather price data for products from the iron and steel industries. Price information can be obtained on hot and cold rolled products such as coil, sheet, wire, rods, bars, tubes, etc. For this research we used price information for hot rolled coils and for cold rolled coils. These price data were considered to be representative for the majority of the steel products according to one data vendor.[16]

Figure 5 A photo of cold rolled coil

Source: Wikipedia.

In order to estimate the model as outlined in Chapter 3, the US is chosen as the alternative market. US producers were not being faced with higher carbon costs during the period of investigation (2005-2009). The EU price data are administered by the data vendor as prices in Northern-Europe and do therefore not represent a full EU perspective. However, in the remainder of this chapter we will refer to them as to EU prices. The US prices were administered as part of the "Northern American" prices, but we will here also refer to the US in the remainder of this chapter.

Both markets are administered per month. The European prices are administered in Euros, the US prices are administered in Dollars. For ease of presentation all series are transformed into Euro prices. Figure 6 and Figure 7 give the development of steel data over time.

[16] MEPS, telephonic consultation, September 2009.

Figure 6 Hot rolled steel price developments in EU and US markets 2001-2009

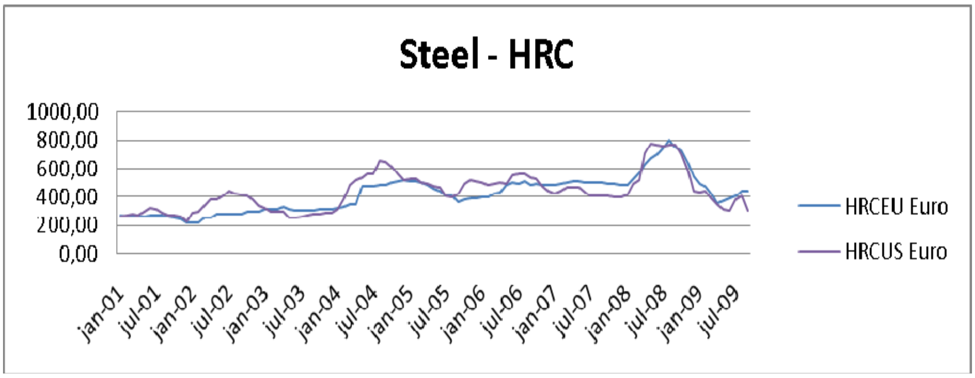
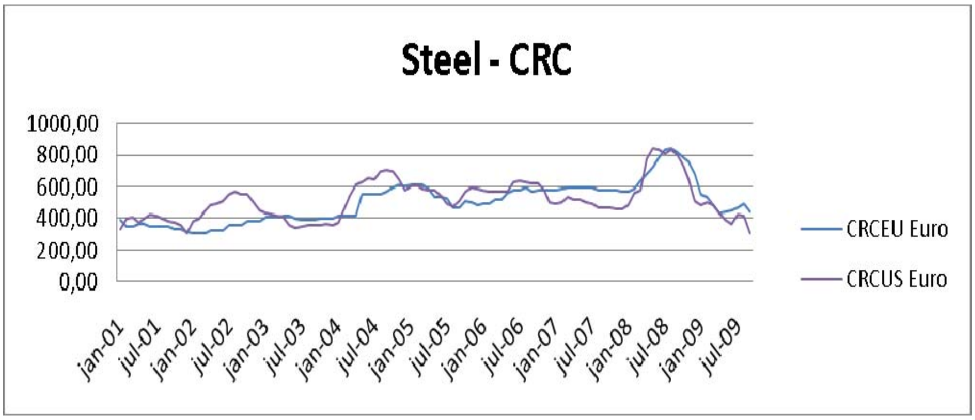


Figure 7 Cold rolled steel price developments in EU and US markets 2001-2009



Prices for both steel products seem to present entangled behaviour. The US prices are mostly higher than EU prices in the period 2001-2006 but mostly lower than EU prices in the period 2007-2009. The US prices seem to be more volatile than the European prices.

4.2.2 Market integration

For both products, the relationship between European and American prices is tested on co-integration. Table 4 gives the results of the Johansen trace tests. As can be seen, the Johansen co integration tests clearly reject co integration between European and American markets for both products. However, if CO_2 is included as an exogenous variable, the prices in the hot rolled coil market does show some signs of co-integration at the 5% level. If CO_2 is included as endogenous variable, again there is no sign of co-integration.

Table 4 Tests for market integration

Co-integration tests	Without CO_2	Model	Lags	With CO_2 as exogenous		Lags	With CO_2 as endogenous	Model	Lags
CRC (EU and US)	17.0019	1	1	16.21516	1	1	22.19075	2	1
HRC (EU and US)	17.96592	2	1	29.4124*	4	4	22.80456	2	1

Note: * Indicates significance at the 5% level. ** at the 1% level. ^: Model depends on the inclusion of coefficients or trends in the co-integrating relationship (see Annex B.1).

Hence below we will start with estimating the model without co-integration. For hot rolled coil we will also present an estimate with co-integration.

4.2.3 Estimation of the non-co-integrated relationship

If no co-integration can be detected between the two series, alternative models come into play according to the estimation procedure outlined in Chapter 3. First, a check on Granger Causality is being performed to investigate whether a VAR is a good alternative for estimation. If there is no Granger Causality, an ordinary least squares estimation on the first differences is appropriate. The Granger Causality tests showed that prices for CRC do not Granger cause each other, but that the HRC market does present Granger Causality in both directions. Therefore a VAR specification is used for the HRC markets while for the CRC market a simply OLS estimation will be conducted.

Using the estimation procedure, as explained in Chapter 3, the main results of both estimates are given in Table 5.

Table 5 Optimal estimation for steel products assuming no co-integration: selected variables

	Dependent variable	Δ (HRC_EU)	Δ (CRC_EU)
	Type of model	VAR	OLS
a	Δ (US price),	**0.173917**	**0.135864**
	[t-stat]/lag	**[1.919] / 1**	**[1.6237] /1**
b	Δ (EU_price),	**0.32542**	**0.24234**
	[t-stat]/lag	**[2.485] / 1**	**[2.1230] / 1**
c	Δ (CO_2)	**2.19318**	**2.20621**
	[t-stat]/lag	**[2.308] / 1**	**[2.2925] / 1**
	Lag	1	1
d	Control variables	Exchange rates	Exchange rate, AEX
	R2adj	0.565881	0.589681

Notes: Figures in bold present significant variables below the 10% significance interval. R2 represent R2 from EU relationship in the VAR. In the VAR also the US market was estimated (not given in this table).

Table 5 gives the main information from the regression output. It shows that the change in EU prices is explained by reference to four variables:

a First, the price level of the US market shows that EU prices will rise if US prices are higher. For every Euro higher prices at the US market, EU prices will increase by about 17 Eurocents for HRC and 14 Eurocents for CRC.

b The price change in the previous period in the EU is an important variable as the price change in the EU market depends for HRC for 35% on the price change in the previous period.

c Third, the price change in the CO_2 markets has a positive and significant influence on the price changes in the EU. These estimates show that a 1 Euro higher price for EUAs is transferred to a higher price of € 2.19 for hot rolled coil and € 2.20 for cold rolled coil. Both CO_2 prices are significant at the 5% level.

d For both steel products, exchange rates were included as an important control variable.

4.2.4 Estimation of the Vector Error Correction Model

The co-integration tests for CRC and HRC show no co-integration between the EU and US price levels. However, including CO_2 as an exogenous variable in the co-integrating relationship shows that there exists possibly a co-integration relationship for the model with HRC (hot rolled coil). This implies that a vector error correction model can be estimated according to the estimation procedure outlined in Figure 4. The outcome of this estimation is presented in Table 6.

Table 6 **Optimal estimation of the Vector Error Correction Model for HRC: selected variables**

	Dependent variable	**Δ (HRC_EU)**
a	Co-integration relation	P_EU = 303.5 + 0.389PP_US
	Lags endogenous	1
a	Adjustment coefficient EU	**-0.24234**
	[t-stat]	**[-5.149]**
a	Adjustment coefficient US	**-0.24173**
	[t-stat]	**[-2.748]**
b	Δ (HRCUS)	**0.22083**
	[t-stat]/lag	**[2.880] / 1**
c	Δ $(_{CO2})$	**2.303931**
	[t-stat]/lag	**[2.872] / 1**
d	Control variables	AEX, Exchange rate
	R2adj	0.75753

Notes: Figures in bold present significant variables below the 10% significance interval. R2 represent R2 from EU relationship in the VECM. In a VECM also a relationship for the US market is estimated (not given in this table).

The change in HRC prices in the EU is according to this optimal estimation dependent on:

a The deviations in the long-run equilibrium relationship. The long-run equilibrium relationship is given in the second row of Table 6. This relationship shows that prices in the EU are best described, in the long run, by the model of € 303 + 39% of the level of the US prices. Deviations from this long-run equilibrium will translate themselves through the adjustment coefficients. The estimated coefficients show that if steel prices in EU are € 1 higher due to an external shock, this will have the consequences that steel prices in the EU will be lower by 24 Eurocents the next period. One should notice that the adjustment coefficients in the US are also negative.[17]

b The change in US prices, Δ (HRCUS), as indicated by the coefficient of 0.22083. This indicates that a change in US prices is for 22% translated in a change in EU prices.

c The positive and significant coefficient of CO_2 prices of 2.303931. This value indicates that if CO_2 prices increase by € 1, the European steel prices will increase next month by about € 2.3.

d Other lagged variables that have been used to control the estimation. Lagged variables included here are the exchange rates and the development of the Amsterdam stock exchange market. Also the past values of the dependent variables are standard included in the error correction model.

Hence, this estimation assumes, just as before, that the CO_2 prices are passed through in the product prices with the lag of 1 month. The value of the coefficient is almost the same as the estimate from the VAR specification in paragraph 4.2.3.

[17] This is contrary to intuition because one should expect that higher prices in the EU due to an external shock reduce prices in the EU and increase them in the US due to more imports. However, this may not be the case if there is a 3rd party (e.g. Chinese steel) that makes prices fall in the EU and in US as well compared to the long-term equilibrium.

4.3 Interpretations

The empirical estimates show that there is some evidence that (part of) the prices of emission allowances have been passed through in the costs of European product steel prices with a lag of one month. The estimates show that for every Euro increase in the EUAs, about € 2.2 price increase will be passed through into prices of both hot rolled and cold rolled coils. Given an average price of about € 500 for hot rolled coil and € 580 for cold rolled coil, this relates to about 0.4% price increase for both products for one Euro price increase in EUAs.

The coefficients of 2.2 can be compared to the information from LCA-databases, such as Ecoinvent. From Ecoinvent we derive a figure for HRC of 1.87 tCO_2/t product and for CRC an emission factor of 1.97tCO_2/t. It should be noticed that these emission factors lay very nearby our estimates. This shows that the empirical analysis provides evidence that the iron and steel sector have passed through the full opportunity costs of their freely obtained allowances into the product prices. Because the size of our estimates is very near to the estimates from the LCA databases, we gain some trust that the coefficients are unbiased.

The full cost-pass-through may have fuelled import substitution. However, this cannot be determined in these empirical estimates. Hatch Beddows (2007) expected that when costs are fully translated into prices, import penetration is expected to rise by up to 5%.

The full cost-pass-through can be partly explained due to the fact that emission prices have been relatively low in Phase 1 and Phase 2 of the EU ETS. IEA (2005a) calculated that transport costs for HRC steel are high enough to avoid import penetration as long as CO_2 prices are under € 28 per ton CO_2, thereby indicating that full pass through is possible[18]. Also the capacity rates can provide an explanation for the full cost-pass-through. Between 2006 and 2008, the European steel industry was characterized by a period of nearly 100% capacity utilization (CIEP, 2009). This has triggered steel prices to rise and may have provided a rationale for passing through the costs of the freely obtained allowances into the product prices. Moreover, this has resulted in imports to increase to satisfy the still growing demand for steel in the EU. During the period of full capacity utilization, especially the imports of intermediate goods from Russia and Ukraine have increased significantly. In a way this can be regarded as profit maximization: chunks of raw unfinished steel were put in the furnaces of EU producers to remelt for specialities products: in this way a higher profit margin could be achieved. As EU steel producers most likely have passed through (part of the) costs of the EU ETS, this also implies that free allocation has introduced a special type of carbon leakage *within the EU firms*.

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18 These freight costs estimates cover the period 1996-2004. Since then, transport costs are even higher due to continuing rising oil prices.

4.4 Conclusions

The steel industry itself claims there is no scope for the steel sector to cover the cost of auctioned emission rights (CEPS, 2008).[19] However, the analysis here shows evidence that this might not be true. We find positive signs that steel industries were able to pass through the costs of EUAs into the product prices, up to 100%. As these allowances were obtained at no cost, these results suggest that the iron and steel sector has made substantial windfall profits during Phase 1 and 2 of the EU ETS. In addition we find some evidence of carbon leakage within the iron and steel sector where the most polluting production processes seem to have been passed through to Russia and Ukraine. This was rational from a cost perspective as EU manufacturers were facing shortage in capacities, but it may have been adding to the windfall profits that were being made in the iron and steel sector, resulting in the over-allocation in the iron and steel sector as observed in Sandbag (2009).

19 That view was already challenged in a number of other studies, such as Climate Strategies (2007). Under the assumption that the competitiveness impact of an emissions trading scheme would be identical to that of a homogenous carbon tax, a cost-pass-through rate of up to 60% can be assumed.

5 Results: refineries

5.1 Market and product outline

Refineries are very large complex industrial plants converting crude oil to a large range of products, from asphalt to fuel gas based on various crude oil grades (IEA, 2005b). The refining sector has been responsible for nearly 3.5% of the direct EU-25 CO_2 emissions (Climate Strategies, 2007). In addition, using the products from the refinery sector creates additional CO_2 emissions: these are however not attributed to the sector.

The refining process can be split into three parts (McKinsey, 2006):
1. Separation: the crude oil is broken up into its components, for example, via distillation.
2. Conversion: depending on the end products required, several intermediate streams can be converted, typically by further breaking up molecules.
3. Finishing: this means that different intermediate streams are blended to achieve the desired qualities, and impurities are removed.

Within the EU, Northern European countries tend to produce relatively high valued products, such as automotive fuels or inputs for the chemical industry. Southern Europe generates a large proportion of fuel and gas oils, although this is slowly changing as industrialists and power generators in this region are switching to natural gas as a heat or power source (IEA, 2005b). The industry faces a challenge since there is an increasing global demand for refined products and at the same time a worldwide tendency to shift to cleaner fuels (IEA, 2005b).

The European refineries have, on an individual basis, limited possibilities to influence market prices at the EU market, both upstream and downstream of the value chain. First, the price of crude oil is fixed across Europe, whereas refinery products are treated as commodities. Prices are set by market operators quoted in specialized energy reviews including the Platt's and Argus. Contracts for supply of refined products are generally based on these quotations (IEA, 2005b). Second, crude production, refining and distribution/retail are still separate businesses. There are a number of large oil companies active in all segments but their operations are not vertically integrated because there are open markets in between. All crude oils enter the international market and very few EU refiners use their 'own' crude. This gives producers the opportunity to maximize the value of their crude while giving refiners the opportunity to optimize their crude slate. A large proportion of EU retail is in the hands of independents that are not refiners. Refiners compete with importers to supply them. Such trade exposure would be most pronounced for motor spirits, where the overwhelming portion is imported or even residential fuel oils with an import share of almost half (CEPS, 2008).

Yet, there is also strong indication that the EU refinery sector as a whole might have enough market power to be price makers at the moment. There is a strong demand for refinery products in high growth regions with insufficient refining capacity such as China, Asia, and North America. In addition, the amount of EU imports is limited by the capacity of foreign refineries to meet European demand and its specific quality and environmental specifications (for example on sulphur levels) (McKinsey, 2006; IEA, 2005b). These requirements form high entry barriers for new (foreign) producers on the EU market. In certain product market segments, European refineries almost exclusively supply several European countries (IEA, 2005b). This holds for the provision of aviation gasoline, motor gasoline and fuel oil.

5.2 Empirical analysis

5.2.1 Price data

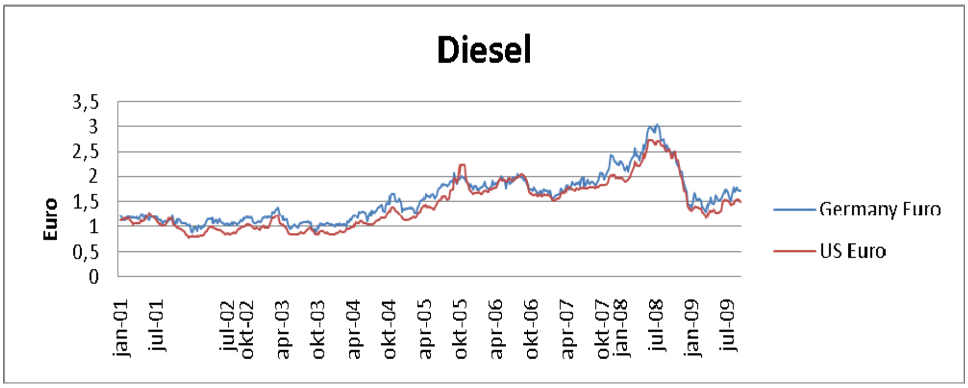
We selected price data for the following products: gasoline, diesel, gasoil and kerosene. Of these price data, kerosene proved to give higher order serial autocorrelation in all estimates, implying that the kerosene prices cannot be analyzed using the here applied econometric techniques.

For diesel and gasoline we compare the German market with that of the US. Price data reflect here the pump prices excluding taxes. Price data were sampled on Monday morning. Gasoil series are available for the harbours of Rotterdam and Singapore, where the prices reflect the so-called 'free on board' rates: the rates excluding shipping.

These series express a reasonable amount of correlation between all variables. In order to control for the estimation we added price data on crude oil barrels: Brent and Cushing. The ratio between Brent and Cushing prices can be expressed as a crude oil exchange rate: this proved to be co-integrated with the price variables in most cases. By including them in the estimates for gasoline and diesel, an estimate could be obtained that was free from higher order serial autocorrelation.[20]

The series are shown in Figure 8 and Figure 9 where all data have been converted to Euros.

Figure 8 Diesel prices excluding taxes in Euros/gallon for Germany and US

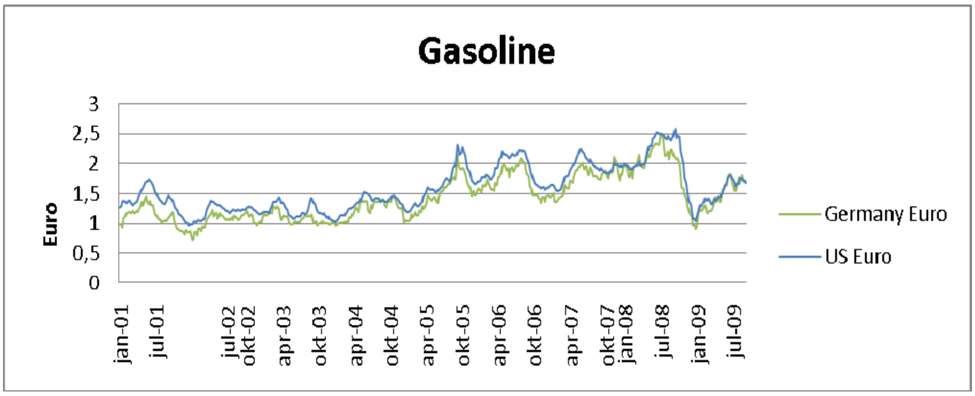


Visual inspection of the data reveals that the diesel prices seem to move together. The German prices are in general higher than US prices. From October 2005 till July 2007, prices move closer together.

20 Without this crude oil ratio included, the estimates were plagued by higher order serial autocorrelation.

For gasoline the picture seems somehow reversed (see Figure 9) as US prices tend to be higher than German prices. This is not so surprising however, as diesel is much less frequently used in the US compared to EU. The diesel and gasoline markets between the US and EU are characterized by the fact that American refineries tend to export diesel to Europe and European refineries tend to export gasoline to the US.

Figure 9 Gasoline prices excluding taxes in Euros/gallon for Germany and US



5.2.2 Market integration

For all three products, the relationship between the EU and non-EU prices is pretested for co-integration. Table 7 gives the results of the Johansen trace tests. As can be seen, the Johansen co-integration tests clearly indicate co-integration for all series. If we include the price ratio between the crudes (Brent compared to Cushing), the co-integration relationship is even stronger for diesel and gasoline[21].

Table 7 Tests for market integration for refineries products

	Plain relationship			With Crude price ratio		
Product	Trace-test	Model	Lags	Trace-test	Model	Lags
Diesel (DE and US)	30.2325**	1	1	62.9194**	2	2
Gasoline (DE and US)	61.8050**	2	1	90.0195**	2	2
Gasoil (Rotterdam/Singapore)	42.4125**	1	1	40.6429**	1	2

Notes: Model depends on the inclusion of coefficients or trends in the co-integrating relationship (see Annex B.1). * Indicates significance at the 5% level and ** at the 1% level.

According to the scheme presented in Figure 4, this implies that we will estimate the Vector Error Correction Model and investigate the influence of the exogenous variable CO_2 on the prices in the EU. For both gasoline and diesel, it proved that the model with inclusion of the crudes price ratio in the long run equation fared much better with respect to autocorrelation and therefore this model is being estimated. For gasoil, inclusion of this variable did not solve issues with respect to autocorrelation and therefore this relationship is being estimated without the price ratio between the crudes.

21 In the case of diesel, a second co-integrating relationship is only excluded at the 1% level (but not at the 5% level). Nevertheless we estimate in the analysis below only one co-integration relationship.

5.3 Estimation outcomes

The outcome of the Vector Error Correction Model for the three price relationships is presented in Table 8 where the main coefficients are being summarized.

Table 8 Outcome of the Vector Error Correction Model estimation for refineries products

	Dependent variable	Diesel ΔP_DE	Gasoline ΔP_DE	Gasoil ΔP _Rotterdam
a	LT Relation	P_DE = 1.253 P_US + 8.979Crudesratio - 9.350	P_DE = 0.8417P_US - 9.263Crudesratio + 9.3496	P_Rdam = 1.0237P_Sing.
	Lags endog.	2	3	1
a	Adj. coeff. EU	-0.004554	-0.007138	**-0.155424**
	[t-stats]	[-0.19912]	[-0.29869]	**[-2.44619]**
a	Adj. coeff. US	0.009317	0.015752	-0.01274
	[t-stats]	[0.69817]	[1.09018]	[-0.19516]
a	Adj. coeff. crudes	**0.029036**	**-0.02781**	Na
	[t-stats] (lags)	**[4.53459]**	**[-4.32631]**	Na
b	ΔPrice_US	**0.53918**	**0.594541**	-0.072614
	[t-stats] (lags)	**[3.80669] (1)**	**[4.22837] (1)**	[-0.55180] (1)
c	Δ (CO_2)	**0.007129**	**0.008002**	**0.009007**
	[t-stats] (lags)	**[1.8377] (2)**	**[1.9904] (2)**	**[3.2598] (2)**
d	Control variables	Exchange rate (lags)	Exchange rate, Dow Jones (lag)	Exchange rate, Dow Jones
	R2adj	0.21124	0.196558	0.304097

Notes: Figures in bold present significant variables below the 10% significance interval. R2 represent R2 from EU relationship in the VECM. In a VECM also a relationship for the US market is estimated (not given in this table).

The top row in Table 8 gives the dependent variable, which is the change in European prices of diesel, gasoline and gasoil. Price changes of these products depend on:

a The deviations in the long-run equilibrium relationship. The long-run equilibrium relationship is given in the second row of Table 8. For Diesel and gasoline the equilibrium relationship includes the difference between a constant and the price ratio between EU and US crudes. More interesting is that diesel and gasoline equilibrium relationships seem to be mirrored according to this estimate. This would suggest that there is a cross-relationship between diesel and gasoline prices in the sense that higher diesel prices in the EU are accompanied by higher gasoline prices in the US. For gasoil, a simple model where prices in the Rotterdam harbour are 2.3% higher than in Singapore seem to be the best fit for the equilibrium relationship. If EU prices are higher than this equilibrium relationship, a downward adjustment process will start for the EU prices. However, for diesel and gasoline this is not significant and eventual price shocks tend to spread onto the market of crude oils.

b The lagged changes in both EU and non-EU prices. The coefficient for diesel for example indicates that if US diesel prices rise with 1%, EU diesel prices will adopt the next period with a price increase of 0.53%.

c The positive and significant coefficients of CO_2 prices. For both diesel and gasoline pump prices, we obtain an estimated lag of about 2 weeks. For gasoil, the price reactions are immediate indicating that a change in spot prices on the CO_2 market is passed through onto the gasoil market immediately.

d Other lagged variables that have been used to control the estimation. Lagged variables included here are the change in exchange rates and the change in the Dow Jones index. Notice that all lagged variables must be included in their first differences as all variables contain a unit root.

Hence, this estimation shows that there is indication that the prices of products from the refineries sector are influenced by the development on the CO_2 spot market.

5.4 Interpretations

How should we interpret the coefficients as given in Table 9? The production of diesel and gasoline has emission factors in the literature of about 509 and 402 grams per litre respectively (CE, 2008b). For gasoil one could use the emission factor for diesel oil. The product prices in the estimates were in gallon so we need to convert these values to gallons. These emission factors are thus equivalent to 1.9 kg per gallon for diesel and 1.5 kg per gallon for gasoline, or 0.0019 t/gallon for diesel and 0.0015 t/gallon for gasoline.

These emission factors can now be compared to the estimates for the coefficient of CO_2, which was 0.071 for diesel and 0.008 for gasoline. What is immediately striking is that the estimate for cost-pass-through is about 3.5 times higher for diesel and more than 5 times higher for gasoline. This is at first sight an unexpected result. However, one should notice that the estimates as presented in Table 8 have confidence bounds and the coefficients can be substantially lower while still staying within the confidence bound. The value for gasoline of 0.08 has, for example, a 95% confidence bound of 0.0001 to 0.015. Hence, the emission coefficients simply lay within the 95% confidence bounds of these estimates. Therefore, a 100% cost-pass-through is still very likely for these estimates, even though the central value suggests even higher cost-pass-through rates.[22]

5.5 Conclusions

The oil industry itself has argued that EU refineries may find it difficult to raise prices enough to fully cover additional CO_2 costs. For costs above € 20/ton of CO_2e, many non-EU importers could increase market share. As to refining, the industry has claimed that a price of € 30/ton of CO_2e would largely wipe out margins (CEPS, 2008). However, the analysis in this chapter shows that the refineries sector most likely has been able to pass through the full costs of their freely obtained allowances in product prices.

[22] One other explanation could be that prices of refineries outputs influence each other. If, for example, prices of gasoline also depend on prices of diesel, a cumulative impact of CO_2 cost-pass-through could indeed occur, even though this is not intended by the refineries in the first place.

6 Results: chemicals

6.1 Market outline

Chemicals is a complex sector that comprises of 20 sub sectors with various types of production processes and outputs. Subsequently, CO_2 emissions and the successive impact of the EU ETS may vary widely. Worldwide, EU-27 is the largest production region of chemicals. The EU basic chemical production is, however, dominated by a few countries. Germany is on top, followed by, France, UK, the Netherlands, Belgium and Ireland (NERI et al., 2007a). In terms of turnover, the petrochemical industry is the most important sub sector.

The petrochemical industry produces chemicals using natural hydrocarbons (e.g. fossil fuels) as major raw materials. By cracking the hydrocarbons and transforming them, a wide number of plastics are being produced. With the Middle East expanding in production capacity and Asia being the biggest growing demander of petrochemicals, the EU industry faces itself nowadays in a transformation towards high-end products to remain competitive.

6.2 Empirical analysis

The chemical markets under investigation are:
1. Polyethylene (PE).
2. Polystyrene (PS).
3. Polyvinylchloride (PVC).

6.2.1 Price and product data

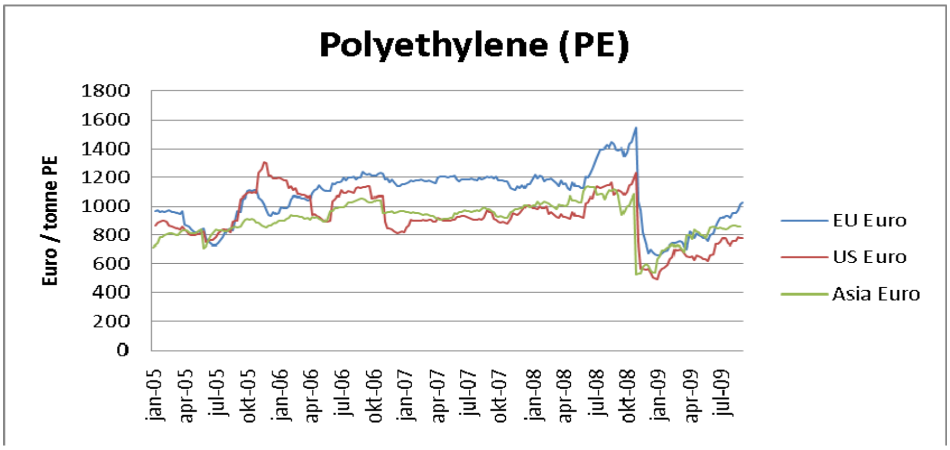
Price data for these markets are administered on a weekly basis in Euros (for European markets) and dollars (for American and Asian markets). For the estimation we have transformed all series in Euros.

Polyethylene

Polyethylene (PE) is a thermoplastic commodity made by the chemical industry and heavily used in consumer products. Polyethylene is cheap, flexible, durable, and chemically resistant. PE is normally characterized by two forms: low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE is used to make films and packaging materials, including plastic bags, while HDPE is used more often to make containers, plumbing, and automotive fittings.

Figure 9 shows the development of prices of PE over time. For PE, especially the Asian and US prices seem to move together. The EU market shows a rise together with the US market, from July 2005 till October 2005. The US market moves up even further and the EU market falls towards the level of the Asian market. From January 2006, the US market moves towards the Asian level and stays there. The EU prices rise and pertain a higher level until the start of the credit crisis.

Figure 10 Data for Polyethylene (PE) on the EU, Asian and US markets



Polystyrene

Polystyrene is a type of polymer with thermoplastic properties produced from the petroleum-derived monomer, styrene. In solid form, polystyrene is a colourless and rigid plastic. However, this material may also be returned to a liquid state by heating and used again for moulding or extrusion. It is used to produce many products for industrial and consumer use. In fact, its presence as a plastic in consumer products is second only to polyethylene.

Figure 11 Data for Polystyrene (PS) on the EU, Northern American and Asian markets

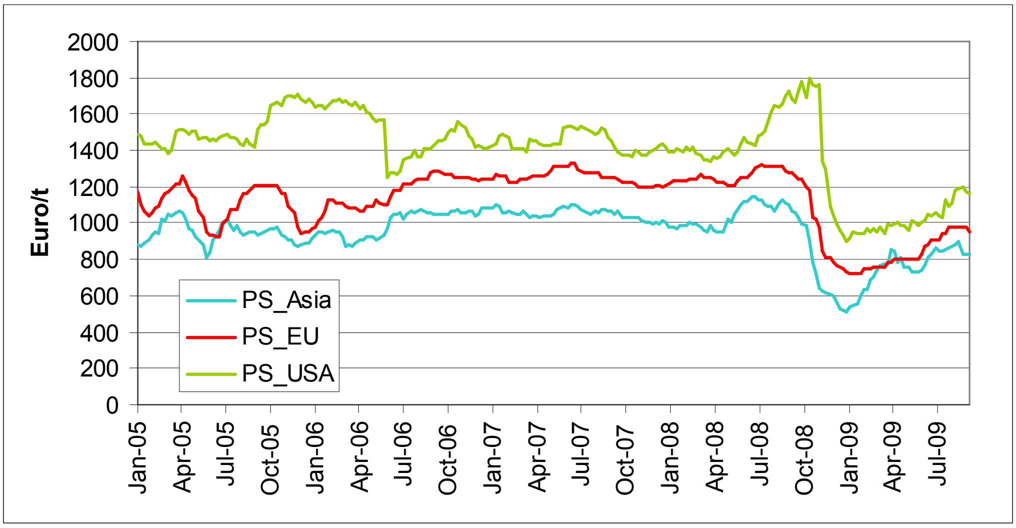


Figure 11 shows the price developments between the various markets. Remarkable is that there are persistent price differences between the markets. US prices are always higher than EU prices and EU prices are virtually always higher than Asian prices. There seems to be more common movement between EU and Asian markets than between EU and US markets - however this is probably due to the fact that price data for both EU and Asian markets reflect spot prices whereas the US markets reflect domestic bulk prices.

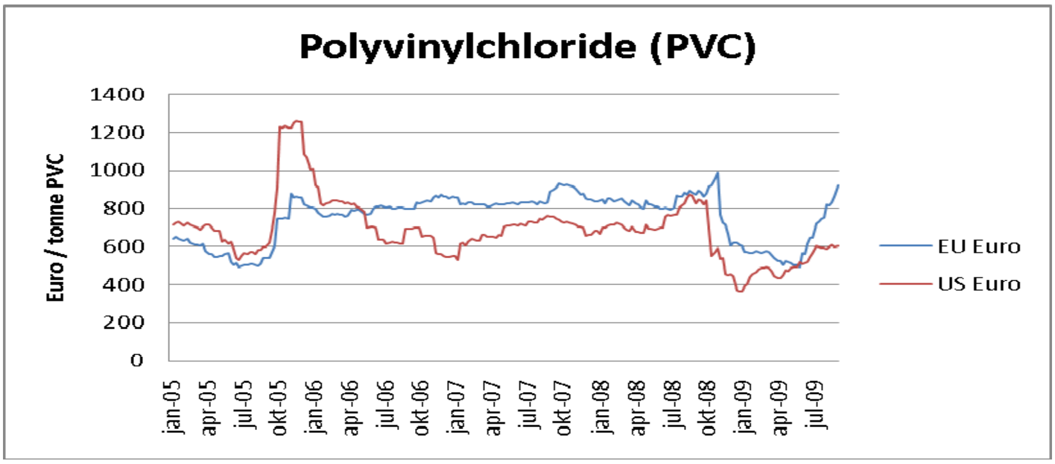
Polyvinylchloride

PVC is produced from the polymerisation of Vinyl Chloride Monomer (VCM). It is a versatile thermoplastic with a wide range of uses including pipes and fittings, profiles, cables, flooring, films and sheets. At least 50% of the market is driven by the construction/housing industry due to the characteristics of PVC: it is cheap, durable and easy to assemble.
PVC is made from chlorine and polyethylene. Since about 57% of its mass is chlorine, creating a given mass of PVC requires less petroleum than many other polymers. However, because PVC also has a much higher density than hydrocarbon polymers and chlorine production has its own energy requirements, the total CO_2 content in producing PVC is in similar range to the other polymers.

PVC is internationally heavily traded. While chlorine is difficult to transport due to safety considerations, PVC is stable (under normal temperatures and pressures) so that transport is relatively easy.

Figure 12 gives the price developments for PVC in the US and EU markets. Prices seem to move together, though less clear than for the other chemical markets. Remarkable is that EU prices are *higher* than US prices here. This is, however, due to the fact that US prices reflect contract prices for both pipe and general-purpose grades, whereas EU prices reflect spot prices for domestic resin and imports from Central and Eastern Europe. In Annex A.1 the price data are described in much more detail.

Figure 12 Data for Polyvinylchloride (PVC) on the EU, and US markets



6.2.2 Market integration

For all three products, the relationship between EU and other markets are pretested for co-integration. In general, the EU and US markets seem not to be co-integrated with each other. PVC prices in the US are almost co-integrated with European prices if CO_2 is included as an exogenous variable; however, this still fails to pass the 5% critical threshold.

Table 9 **Outcome of the trace tests for chemical products**

	PE_US	PE_Asia	PS_Asia	PS_US	PVC_US
Without CO_2	13.697	23.764**	7.3625	10.512	14.339
Model	2	2	2	2	2
Lags	1	1	1	3	1
With CO_2 as exogenous	13.963	37.425**	15.135	15.062	19.242
Model	2	1	2	2	2
Lags	1		1	3	1
With CO_2 as endogenous	22.632			35.516*	26.711
Model	2			2	2
Lags	1			1	1

Notes: Model depends on the inclusion of coefficients or trends in the co integrating relationship (see Annex B.1). * Indicates significance at the 5% level and ** at the 1% level.

For this reason we arrive at the following estimation procedure (see Table 10). Notice in Table 10 that although the PVC Granger Causality tests suggest that a VAR might be more appropriate, this estimate is plagued by serious higher order autocorrelation – which is more or less absent in the OLS estimates. Therefore, we present in the next subparagraph an OLS estimate for PVC.

Table 10 **Estimation procedure for chemical products**

Johansen Trace/Max. Eigenvalue Tests and Granger Causality	Co-integration	Co-integration with CO_2_ex	Granger Causality	Preferred Model
Polystyrene EU vs. Asia	no	yes	-	VECM
Polystyrene EU vs. US.	no	no	yes	VAR
Polyethylene EU vs. US	no	no	no	OLS
Polyethylene EU vs. Asia	yes	-	-	VECM
Polyvinylchloride EU vs. US	no	no	yes	VAR

6.2.3 Estimation for the US market

Although the estimation procedure pointed at estimating a VAR for PE and PS for the relationship between European and US prices, it proved that the resulting VARs were heavily influenced by higher order serial autocorrelation that could not be removed. Therefore, both for PVC and PS an OLS model was estimated which fared much better with respect to autocorrelation, especially for PVC. For PE, OLS was already identified as the optimal model selection.

Hence, for prices of PVC, PE and PS in the US, an ordinary least squares estimate was executed. The outcome of this estimate is given in Table 11.

Table 11 Outcome of the OLS estimates for chemical products

	Dependent variable	Δ (PVC_EU)	Δ (PE_EU)	Δ (PS_EU)
	Type of model	OLS	OLS	OLS
a	Δ (US price)	**0.304422**	**0.593959**	**0.093805**
	t-stat (lags)	**[6.27745] (4)**	**[13.5557] (0)**	**[3.503813] (0)**
b	Δ (EU_price)	**0.131184**	**0.210803**	**0.170997**
	t-stat (lags)	**[2.39584] (3)**	**[4.52530] (3)**	**[2.813848] (2)**
c	Δ (CO_2)	**1.595426**	**2.23023**	**1.106152**
	t-stat (lags)	**[2.06654] (8)**	**[1.92375] (4)**	**[1.721517] (3)**
d	Other lagged variables	D(CO2(-19))	d(P_EU(-3,-5))	d(CO2,5,11),d(PEU(3 ,6),dP_US(12)
	Control variables	Exchange rates, DJI	Cruderatio, Dow Jones	Dowjones,exchange, cruderatio
	R2adj	0.3617	0.5562	0.446311
	DW_Statistic	2.013	2.162	1.889672
	Prob Q_18	1.000	1.000	0.847

Notes: Figures in bold present significant variables below the 10% significance interval.

Table 11 shows that the price changes in the European prices of PVC, PE and PS depend on four influences:

a First, the price changes on the US market which is very significant for all products. For PVC the lagged US prices gave the best result, where European prices lag four weeks behind the US prices. A price rise in US prices is for 30% translated into European prices. For PE no delay in price changes can be found. European prices react immediately for about 60% on American price changes. For PS, much less influence is detected where PS price changes on the US markets impact only for 9% on the European market. For PS, some higher order influences of US prices were detected (not given in Table 11).

b Second, the lagged price development in European prices is significant for all variables. For both PVC and PE, a lag of three weeks fitted best. This implies that if European prices of PVC would rise by € 100/tPVC, an additional price rise of € 13 can be recorded after three weeks. For PS, a price lag of two weeks was also significant, in addition to price lags at weeks three and six (not given in Table 11).

c Third, the prices are positively influenced by the price of EUAs. For PVC, every Euro price in the EU ETS markets result in a price increase in PVC of about € 1.6 and for polyethylene of about € 2.2. CO_2 prices are passed on for polyethylene with a lag of four weeks, and for PVC with a lag of eight weeks. Both coefficients are significant at the 10% level (for a two-sided test, or 5% for the one-sided t-test). For PS, the coefficient of CO_2 prices is with 1.1 about half of that of PE. Also this coefficient is significant at the 10% level. For PS some higher order influences could be found that more or less cancelled each other out.

d In the estimates are also included control variables. The Dow Jones index proved to be an important variable in each of the estimates. For PE and PS, also the crude oil prices (reflected as a ratio between the Brent and Cushing prices) were significant.

The very good values for the DW-statistics and Ljung-Box Q-statistics for PE and PVC show that these estimates are not plagued by serial autocorrelation. For PS the number of variables included was much larger and the estimates seem to suffer a bit from serial auto correlation. Also the Ljung-Box Q-statistics do not decay smoothly over time suggesting that some higher order autocorrelation may be present at the estimates, though not significant under the Ljung-Box Q-statistics.

6.2.4 Estimation for the Asian market

For the Asian markets, both a VECM is being estimated for PS and PE. However, higher order serial autocorrelation indicating that the fit of this model is not very good plagued this estimate. Table 12 gives a summary of the relationship between the EU and the Asian markets.

Table 12 Outcome of the estimates of the Vector Error Correction Model for chemical products

Dependent variable	PE_EU	PS_EU
LT Relation	PE_EU = 713,6 + 1,950 PE_US	PS_EU = - 703,6 + 1,505PS_US + 6,897CO2
Lags endogenous	3	3
Adj. coefficient EU	**-0,0830**	**-0,0091**
	[-3.743]	**[-11.636]**
Adj. coefficient Asia	-0,0064	**0,0290**
	[-0,2874]	**2.6801**
D (Price_asia)	**0,1601**	**0,2218**
	[1.6543] (2)	**[4.64] (1)**
D(CO_2)		-0,2379
		[-0,4044] (1)
Exogenous control variables	Exchange rates, Dow Jones	Exchange rates
R2adj	0.243689	0.443365
Portmonteau Q(18_prob)	0.0026	0.4982

Notes: Figures in bold present significant variables below the 10% significance interval. R2 represent R2 from EU relationship in the VECM. In a VECM also a relationship for the Asian market is estimated (not given in this table).

This estimate does not find a significant influence of CO_2 prices for both products. For polyethylene the optimal model selection showed that CO_2 should not be included in the estimates[23]. For PS, CO_2 prices have transferred themselves as endogenous variable in the co-integration relationship. This co-integration relationship suggests that about € 7 of CO_2 prices is passed through in the product price in the long run. However, the short-run influence of CO_2 prices is insignificant.

However, higher order autocorrelation (implying that the t-statistics cannot be used to determine whether variables are significant or not) seriously plagues both estimates. This is probably due to an omitted variable, but within the realms of this research trajectory it has not been possible to reveal this variable. Therefore we conclude that with respect to Asian markets we cannot determine whether EU producers were or were not able to pass through the costs with this model.

[23] Although at lag 13 some influences can be found which are, however, not significant at the 10% confidence level.

6.3 Interpretation of the results

The empirical estimates show that there is evidence that (part of) the prices of emission allowances have been passed through in the costs of European petrochemical products. European prices showed a persistent influence from the developments on the EU ETS markets suggesting that price changes in EUAs are being passed through in the price of these chemical products. Compared to the Asian market, the models chosen here did not yield stationary results suggesting that some omitted variable problem may be persistent there. However, this does not suggest that there has been no cost-pass-through compared to the Asian market: the question whether the costs have been passed through just cannot be assessed with the chosen data and type of models.

The question is how we must interpret the coefficients in terms of the amount of CO_2 that is passed through in the product prices. Table 13 gives the outcome of an Ecoinvent model run for the chosen chemical products:

Table 13 Ecoinvent emission factors in tCO_2/t product

Ecoinvent emission factors	tCO_2/t product
Polyethylene, HDPE, granulate, at plant/RER S	1.918
Polyethylene, LDPE, granulate, at plant/RER S	2.089
Polyethylene, LLDPE, granulate, at plant/RER S	1.839
Polystyrene, expandable, at plant/RER S	3.350
Polystyrene, general purpose, GPPS, at plant/RER S	3.489
Polystyrene, high impact, HIPS, at plant/RER S	3.476
Polyvinylchloride, bulk polymerised, at plant/RER S	1.586
Polyvinylchloride, emulsion polymerised, at plant/RER S	2.484
Polyvinylchloride, suspension polymerised, at plant/RER S	1.895

Note: Equivalence factors based on IPCC 2007 without LULUCF/biogenic.

Hence for PVC, the chosen coefficient for a change in EUAs of 1.595426 (see Table 11) corresponds with the lower values on this estimate for PVC. One should notice, however, that the value of 1.5954 only gives the changes over a week in PVC prices due to changes in EUA prices. Due to the lagged responses in the model, these tend to become higher over time.[24]
The coefficient for PE was estimated at 2.23023. This is slightly above the emission factors presented in Table 13. Finally, the coefficient for PS was estimated at 1.106152. This is considerably lower than the calculated emission coefficients that converge around the 3.4 tCO_2/tPS. Hence here the model estimates that only about 1/3 of the costs will be passed through as a central value, although the emission coefficient still lies within the 95% confidence bounds of our estimates.

Important, however, is that the costs are passed through with a considerable time lag of several weeks. PE and PS are mainly made from input of naphtha from the refineries sector, whereas PVC contains both naphtha and chlorine as prime inputs. The lagged response may be perfectly congruent with the assumption that the petrochemical industry itself is passing through the higher costs of inputs from the refineries and the inorganic chemical industry through in their product prices.

24 In the end, the prices passed through would be equivalent to the emission factor for the suspension polymerised PVC.

6.4 Conclusion

We find evidence that the costs of the freely obtained allowances have been passed through in the product prices also for the chemical industry. This is most convincing for PVC and PE, where the estimated coefficients from our regression analysis are almost similar to the emission coefficients from the Ecoinvent LCA database suggesting a 100% cost-pass-through for these products. For the more CO_2 intensive production of polystyrene, we find less evidence of cost-pass-through. The costs are initially here only passed through for about 1/3 of the expected value from the LCA database.

Although we find evidence that CO_2 costs have been passed through in the product prices, we have no possibility to assess here *who* has done that. So the price increases in the petrochemical products may perfectly the result from the cost-pass-through in the deliveries from the refineries and inorganic chemical sectors. This is supported by the observation that the CO_2 costs seem to have been passed through with a considerable lag in the prices, suggesting that the costs were already borne before the petrochemical products were produced.

7 Conclusions, discussions and recommendations

7.1 Main conclusion

Unilateral climate policies run the risk of carbon leakage where energy intensive sectors face a competitive disadvantage compared to companies that do not fall under a climate policy regime. It is generally believed that protecting energy intensive industry from unfair competition is good for both the economy and the environment. Within the context of the European trading scheme (the EU ETS), the energy intensive industry has successfully pled for free allocation of allowances instead of auctioning. They argued that free allocation would have the least impact on their cost structure so that their prices can stay in line with those of competitors not facing climate policies.

In the revised Directive on EU ETS (2009/29/EC), free allocation was presented as a way to tackle carbon leakage. However, the assumption under which free allocation can be a remedy for carbon leakage is that companies do not pass through the opportunity costs of their freely obtained allowances into their product prices. Otherwise, they would obtain windfall profits and no change in competitive situation compared with auctioning will be achieved.

The question whether energy intensive companies have gained windfall profits from the EU ETS was assessed in this research with the use of econometrics. By using a co-integration analysis framework, it was shown that there is ample evidence that energy intensive companies *did* pass through the opportunity costs of their freely obtained allowances into the product prices. This seems especially the case for products from the iron and steel and refineries sectors. Here the lagged influence of CO_2 prices is relatively short (about one week) giving confidence about these results. For petrochemical products, the evidence is less overwhelming. We do find significant past values of CO_2 prices in the data, suggesting full cost-pass-through for polyethylene and polyvinylchloride and partly cost-pass-through for polystyrene. However, the change in CO_2 prices comes only at a greater lag into the product prices. This could be explained by the fact that the petrochemical industry is primarily being faced with higher costs of inputs due to the EU ETS. If both refineries and electricity producers would have passed through the costs of the freely obtained allowances into naphtha and electricity (used for chlorine production), prices of petrochemical products would rise even if the petrochemical sector themselves would not pass through the opportunity costs. However, this cannot be revealed with the econometric estimation method that we applied.

Regardless of which sector actually did pass through the costs, the conclusion of this research is that substantial windfall profits have been made by energy intensive companies that obtained allowances for free, but calculated their market value in the prices of the products. Therefore, the alleged competitive advantages of free allocation are grossly overstated. Free allocation merely shifts income from consumers to companies without helping the competitive position of companies or the environment.

7.2 Policy implications

Industry claims that their competitive position is seriously at risk if rights are auctioned instead of given for free. This claim must at least be qualified. Econometric research in this study has revealed that EU producers of energy intensive products most likely have widely passed through the opportunity costs of their freely obtained allowances into the product prices. This implies that European climate policies have allowed energy intensive producers to make windfall profits at the expense of the consumers.

The total magnitude of windfall profits is difficult to discern as the evidence was here only shown for a few products in three sectors. However, if we would apply the here discovered full cost-pass-through rates to all products in the refineries and iron and steel sectors, it can be calculated that the total amount of windfall profits would equal € 14 billion between 2005 and 2008.[25] This implies a substantial transfer of money from consumers to the energy intensive industry.

Such a transfer may have negative consequences for the future of economic growth in the EU. As the costs of living of EU citizens will rise, EU citizens may want to pass these costs onto their employers (by demanding compensation for inflation). In that case, the EU ETS would imply a transfer of money from the labour intensive industries towards the energy intensive industries. This is counter-productive for any policy aiming to stimulate the EU as a knowledge economy.

The findings in this study do call for a re-assessment of the allocation basis for the third phase of the EU ETS. The European Commission should reassess the decision not to auction large parts of the emission credits to the energy intensive industry. Auctioning will not only reduce windfall profits but will in general result in lower costs to society and lower emission prices. Auction revenues, however, should be redistributed lump sum to consumers and business to minimize the impacts from an auctioning regime and to reduce eventual carbon leakage. It will politically not be easy to envision a scheme that would fit both the criteria of scientific soundness and political feasibility.

The methods employed in this research could – as an alternative - also be used for the EU to re-assess the allocation basis – both at the start and during the mid-term review of the post-2012 emission trading scheme. It could, for instance, be possible to give companies conditional free allocation that will be withdrawn if analysis of the price data would reveal cost-pass-through.

7.3 Discussions and uncertainties

Relating the influence of EUAs on product prices is like finding a needle in a haystack. Prices tend to fluctuate heavily over time because of a thousand factors and the potential passing through of the opportunity costs of freely obtained allowances may be just one of the possible factors. The confidence one attaches to the estimates presented in this study crucially hinges on the belief one has in our estimation method. The estimation method here developed aimed to prevent data mining and obstructing eventual pre-selection towards cost-pass-through. By setting up an estimation procedure, as outlined in Chapter 3, the chances of spurious results were

[25] Calculated from using the verified emissions from the CITL codes 2 and 5 from the verified emissions between 2005 and 2008.

lowered. However, the results here are dependent on the data and on the estimation method. We see four potential sources of uncertainty that might lead, as a consequence, the results of this research to be reversed in future research.

1. Wrong data. It is of course conceivable that there are mistakes in the price data that we have collected in this research. Although this price data is obtained from commercial data vendors, their pricing information can be wrong. We perceive this risk as small, however, and there is not much that can be done against it. It would disqualify any quantitative work and make empirical research useless.
2. Omitted endogenous variable. It can be the case, of course, that the CO_2 prices have mimicked another phenomenon that is very significant but not included in the estimation. If, for example, CO_2 emissions prices would be influenced by bad weather conditions and if the weather conditions would also influence the prices of European products, we could wrongly conclude that CO_2 prices influence European prices as the underlying phenomenon (bad weather) was not included in the estimates. We consider this chance as fairly low again. It is true, of course, that the general economic situation influences prices of every commodity, but this effect was included in the estimates by including an estimate for the development of indices of the US and European stock exchange. We find it difficult to envision another variable that would simultaneously influence the price developments on the CO_2, European and US markets – but this could not be excluded in the end. So there is a small chance that in the future more extensive models will reveal another variable to be very important.
3. Omitted exogenous variable. It could also be the case that CO_2 prices are correlated but not causally related to the changes in European prices. Suppose for example that the workdays lost due to strikes influence the European prices, resulting in higher prices on the European market due to local shortages. Now suppose that these days of strike very accidentally coincide with CO_2 price developments, one may conclude that CO_2 prices influence the final results while in fact it were only strikes. However, the chance that a certain variable accidentally coincides with CO_2 is very small as the CO_2 prices over time have a quite particular development (as an M-shaped figure) that is not very common in time-series. Therefore we think that the omitted exogenous variable problem is not important here.
4. Specific market conditions. Between 2005 and 2009 the economic situation was quite exceptional. First there was an economic boom where prices were increasing worldwide for virtual all commodities, followed by the collapse in the end of 2008. It has been argued in the literature that especially during times of economic boom, companies may have more opportunities to pass through the costs as capacity rates are fully utilized (IEA, 2009). This is very likely as the situation of underutilized capacity rates make it for firms profitable to sell products at prices below marginal costs. However, our estimates include both the economic boom period and the subsequent economic downturn. Visual inspection of the residuals denied the possibility that the fit of the model is considerably less good in the last year than in the first years. However, it might be possible that in the future the opportunities to pass through the costs will diminish and be smaller than suggested here. But this does not mean that the possibilities to pass through the costs will be absent as both theory and empirics point in this research at the same direction that companies will pass through their opportunity costs and accept an eventual reduction in market shares. Only if a sufficient theory can be developed that would explain why companies aim to maintain market shares and sell products below marginal costs for prolonged periods of time, this can be worthwhile to investigate in empirical research in the future.

5. Model specification and testing. These results have been obtained using Vector Error Correction Models, vector autoregressive models and lagged estimation models where lagged variables play an important role. For refineries and iron and steel we found relatively short time lags of about 1 week between changes in CO_2 prices and changes in EU product prices. However, for the chemical sector we found much longer time lags. These longer time lags are adding more uncertainty to the outcome as the changes of a spurious result due to omitted variables are increasing. For these reasons we think that model specification could still be optimized – but this could either give more or less evidence of cost-pass-through. The outcome is hence not to be predicted beforehand.

Overall, we agree that the results from this study must be interpreted with some caution. There may be reasons why the results obtained here may be spurious or cannot be generalized. However, we do not find any alarming reasons that expand outside the normal realms of empirical research. We have tested here the economic theory that companies would pass through the costs of their freely obtained allowances and all statistical methods employed in this research have found support for this economic theory. As theory and empirics point in the same direction, we can perceive this as pretty strong evidence.

7.4 Directions for further research

Possible expansions for further research are related both to the method development and application. The method developed here could be further refined by estimating the EU price developments not only in combination with the US market but with a range of markets through which a structural equations model is estimated. This would imply that the full set of market adjustments is made visible. Eventual price changes in the EU market could then be translated to the Asian and Northern American markets simultaneously and the impact of a price shock in CO_2 markets could then be investigated in more detail. It could be, for example, the case that higher CO_2 prices would stimulate US imports to the EU but that prices in the US will not rise due to imports from South-East Asia in turn. Such effects are with more precision estimated in a structural equations model where all market relations are simultaneously being estimated.

Another worthwhile extension of this research is to apply the method to more products and prices. It will be interesting to investigate whether other markets are also characterized by cost-pass-through and through this to reveal the underlying critical variables for the question whether companies will pass through the costs of their freely obtained allowances. Insight in the underlying structural variables may help politicians design better instruments preventing carbon leakage than free allocation for all sectors with substantial cost price increases due to the EU ETS.

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Annex A Description of data

A.1 General description

A.2 General description

Steel (monthly)

Source:	Steel Business, see http://www.steelbb.com
Data:	Monthly, in Euros per ton (from 2009 weekly data).
Products:	Hot rolled wide coil (carbon steel), cold rolled coils (carbon steel)
Regions:	North-America, North-Europe
Time period:	January 2001-September 2009
More information:	The data is sourced from executives in the steel business - traders, stock lists, distributors, consumers and producers through telephone interview.

PE

Source:	ICIS, see www.icispricing.com
Data:	Weekly, in US Dollars per metric ton (Europe and SE Asia)
Products:	Polyethylene (bagged), HDPE injection
Regions:	Northern America (polyethylene bagged, export price), North-West Europe (spot, FD, HDPE injection), South-East Asia (spot, HDPE injection)
Time period:	1 Jan 2005-9 Nov 2009
Remarks:	For the real prices, you need to look at the spot prices, because these prices contain the real-time market information. Spot prices are around 5-10% of the total market in Europe and 20% of the total market in the US and Asia. Free delivery (FD) is the price inclusive of transport up to the door, usually for within the continent. Free on board (FOB) is usually the export price exclusive of transport.

PS

Source:	ICIS, see www.icispricing.com
Data:	Weekly, in US Dollars per metric ton (Europe and SE Asia).
Regions:	Northern America (contract prices domestic bulk products), North-West Europe (spot, FD), South-East Asia (spot prices)
Time period:	1 Jan 2005-9 Nov 2009

PVC

Source:	ICIS, see www.icispricing.com
Data:	Weekly, in US Dollars per metric ton (Europe and SE Asia)

In the European PVC Report, spot business primarily relates to imports into Western Europe from Central and Eastern Europe and deep-sea sources, but depending on the balance of the market it may also include domestic resin. Domestic gross (untaxed) price quotes refer purely to regular West European business between producer and consumer on a contracted basis. This is normally agreed on a monthly basis, but the length of price agreements may vary depending on the dynamics of the market at the time.

In the Asia Pacific PVC report, spot business functions on a monthly pricing mechanism related to exports from Japan, Taiwan and Korea into Hong Kong, China, southeast Asia and non-China markets. Producers nominate target prices and these are applied or otherwise, subject to market conditions. Export prices are also reported on FOB CHINA ethylene-based and FOB CHINA carbide-based PVC as China has become a primary exporter of PVC. Prices that relate to domestic supplies in China are mentioned in the report text.

The US domestic PVC market functions on a monthly contract pricing mechanism for both pipe and general purpose grades. Contract prices are assessed based upon delivered prices to medium-sized accounts, purchasing 50-100 m lb of PVC resin per year. These prices do not include discounts. Producers nominate target increases and these are applied or otherwise, subject to market conditions. Prices relate to domestic supplies from the USA, Canada and Mexico. Export prices are also reported on an FOB US Gulf basis. Latin America has historically been the major destination for US PVC exports, but US material is now shipped to countries all around the globe.

Diesel, Gasoline

Source:	Oil bulletin from EIA, see: http://www.eia.doe.gov/emeu/international/oilprice.html
Data:	Weekly, in US Dollars per gallon excl. taxes
Products:	Retail diesel, Retail premium gasoline
Regions:	Germany, US
Time period:	1996-present
Remarks:	Member states report their retail prices of oil products to the Commission. These data are partly obtained through oil companies. German data are missing if the Monday was a holiday. In that case the average has been taken from the week before and after.

Gasoil

Source:	EIA, http://www.eia.doe.gov/emeu/international/oilprice.html
Data:	Weekly, in US Dollars per gallon excl. taxes
Regions:	Port of Rotterdam, Port of Singapore
Time period:	1996-present

A.3 Statistical description of the data

Below the information is given on the nature of the data that have been used in the regression analysis. In some cases we have transformed the original data in Dollars to Euros: this is indicated by an asterisk in the table as well. Table 14 gives more statistical information on each of the weekly series and Table 15 of the monthly series.

A.4 Statistical description of the data

Table 14 gives more statistical information on each of the weekly series and Table 15 of the monthly series.

Table 14 Descriptive statistics, weekly series, 20-6-2006 to 07-09-2009

	Unit	Mean	Median	Max.	Min.	St. Dev.	Observations
CO_2	€/t	13.6	14.6	29.6	0.0	9.5	221
Diesel_DE	$/gallon	2.65	2.40	4.78	1.70	0.70	221
Diesel_US	$/gallon	2.48	2.35	4.30	1.55	0.64	221
Gasoline_DE	$gallon	2.35	2.33	3.91	1.29	0.55	221
Gasoline_US	$/gallon	2.55	2.53	3.95	1.47	0.56	221
Gasoil_Rdam	$gallon	2.09	1.89	4.12	1.16	0.66	221
Gasoil_Sing	$/gallon	2.04	1.84	4.15	1.10	0.66	221
PVC_EU*	€/t	772	815	990	490	120	219
PVC_US*	€/t	688	687	1262	363	171	219
PVC_Asia*	€/t	649	649	836	452	84	219
PS_EU*	€/t	1129	1210	1330	725	175	219
PS_US*	€/t	1406	1428	1802	898	221	219
PS_Asia*	€/t	954	993	1144	515	142	219
PE_EU*	€/t	1084	1148	1549	661	190	219
PE_US*	€/t	930	924	1311	490	176	219
PE_Asia*	€/t	922	940	1139	527	123	219
Brent	$/barrel	72.2	66.9	141.1	35.4	21.9	221
Cushing	$/barrel	73.2	66.6	142.5	33.0	22.6	221
Crudes ratio	Brent/Cushing	0.99	0.98	1.23	0.87	0.04	221
Exchange	€/$	0.75	0.75	0.86	0.63	0.06	221
AEX	index	418	442	560	207	98	221
Dow Jones	index	11171	11220	14074	6803	1746	221

Notes: For chemical products, the end-date of the observations is 8-8-2008. CO_2 prices included here are for weekly averages. For estimation of the gasoline and diesel products we used CO_2 prices on Mondays which gives similar descriptive statistics but slightly different results. * Transformed to € using exchange rates.

Table 15 Descriptive statistics, monthly series, 06-2005 till 9-2009 used in regression analysis

	Unit	Mean	Median	Max.	Min.	Std. Dev.	Observations
CO_2	€/t	13.8	14.8	27.0	0.0	9.4	52
CRC_EU	€/t	581	578	843	433	102	52
CRC_US*	€/t	557	527	841	306	122	52
HRC_EU	€/t	499	489	798	358	104	52
HRC_US*	€/t	489	466	774	305	121	52
Exchange	€/$	0.75	0.76	0.85	0.63	0.06	52
Dow Jones	index	11152	11233	13900	7213	1747	52
AEX	index	417	444	552	213	99	52

Note: *Transformed to € using exchange rates.

Compared to similar research earlier undertaken in the Netherlands (CE, 2010, forthcoming), these data have been refined. For CO_2 prices, for example, the monthly prices have now been calculated taking the average prices during the month, while in the earlier research the first data in the month was taken as the representative value. This gives small differences in the data used between both studies.

Annex B Econometric procedures

B.1 Trace data

Pre-testing the data on eventual co-integrating relationship takes the form a Johansen trace test. Test-statistics and values are dependent on the chosen model of the long-run relationship.

Model 1: No intercept or trend in the co-integrating equation (CE) or VAR, $H_2(r)=\alpha\beta' Y_{t-1}$.
Model 2: Intercept (no trend) in CE, and no intercept or trend in VAR, $H_1(r)=\alpha(\beta' Y_{t-1}+P_0)$.
Model 3: Intercept (no trend) in CE and VAR, $H_1(r)=\alpha(\beta' Y_{t-1}+P_0) + \alpha\_\gamma_0$.
Model 4: Intercept and trend in CE, and no trend in VAR, $H(r)=\alpha(\beta' Y_{t-1}+P_0+P_1 t) + \alpha\_\gamma_0$.
Model 5: Intercept and trend in CE, and linear trend in VAR, $H(r)=\alpha(\beta' Y_{t-1}+P_0+P_1 t) + \alpha\_(\gamma_0+\gamma_1 t)$.
$\alpha\_$ is here the n x (n-r) matrix such as $\alpha'\alpha\_=0$ and rank $(|\alpha|\alpha\_|)=0$.

In general, model 5 is considered as a rare case and can only be considered if there is some specific economic reasoning for cubistic trends in the data.