Norwegian School of Economics
Bergen, Spring 2019

European Climate Policy and Industrial Relocation

An Assessment of the Ecological and Managerial Impact of the EU ETS on European Manufacturing

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Master Thesis, MSc in Economics and Business Administration, Strategy and Management

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Acknowledgements

Writing a master's thesis is a challenging project that contributes to the academic and personal development. I feel fortunate having been able to study a topic of my own interest, which is also purposeful in a societal context.

The completion of this project has been kept on track with the valuable help from my supervisor, Lassi Ahlvik, whom I must thank for expanding my horizon and showing me different ways how to approach this wide topic, and from whom I regularly received valuable input and feedback. His quick response to any question, his commitment and his very deep knowledge of the topic investigated has been profoundly motivating and guided me throughout the whole process. I also want to thank my friends for supporting me with their beneficial and motivating comments, and for building me up with the Norwegian *risgrøt* in the student canteen. Special thanks go to my father, who gave me advice, discussed critical points and has at times proofread my thesis.

The process of building this thesis has been different from what I initially thought it would be, yet I have learned a lot especially about a topic of great societal significance.

I hope that this work will contribute to the debate on greenhouse gas reduction.

Abstract

Do abatement costs from CO_2 emissions affect a firm's choice to relocate, by that creating carbon leakage? The aim of this thesis is to investigate the accuracy and effectiveness of climate policies in the European Union and thus to question the current allocation mechanism for sectors that deemed to be exposed to carbon leakage. The relationship between abatement costs and relocations risks is assessed by exploiting firm level data on relocations risk and macro level data on CO_2 emissions. Utilizing the fixed effects model approach, a negative effect of abatement costs on relocation risks of those companies that cut CO_2 emissions was found. These finding implies that no evidence for carbon leakage could be drawn from the results and confirms the results of previous research. Two fundamental areas were identified that need to be understood and to be addressed in future research. First, the allocation mechanism of certificates that is being used in the EU needs to be revised since companies are facing an overallocation of certificates while having a low risk of relocation. Shrinking the pool of allowanced available for free allocation would be one potential angle for a substantial change. Secondly, by overcoming the information asymmetry between regulator and regulated, other factors despite facing political restrictions and abatement costs must exist that discourage decision-makers from relocating production facilities abroad. Other variables that might impact the competitive position of sectors should be addressed in future research such as energy costs, labor costs etc. This thesis emphasizes the need for re-opened a debate about the measures to address carbon leakage in the future, including an expansion of options to address this issue. One option could be, instead of overallocation sectors, to reflect upon how best to enforce initiatives for the implementation of "greener" technologies in order to achieve cost savings for companies while limiting CO_2 emissions on the long run.

CONTENTS

Acronyms

BAU	Business as Usual
CCS	Capture and Storage Technologies
CO_2	Carbon Dioxide
CI	Carbon Intensity
EC	European Commission
EEA	European Environment Agency
EU	European Union
EU ETS	European Union Emissions Trading System
EUTL	European Union Transaction Log
GF	Grandfathering
GHG	Greenhouse Gas
GDP	Gross Domestic Product
MAC	Marginal Abatement Cost
NAP	National Allocation Plan
SD	Standard Deviation
TI	Trade Intensity
UK	United Kingdom
VS	Vulnerability Score

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1. Introduction

1.1 Motivation and Purpose

The pollution of carbon dioxide (CO_2) is a global issue in many countries that attracts a great deal of attention. Even though climate change caused by CO_2 emissions represents a global problem, reduction measures are usually only implemented at a regional level. As a result, CO_2 legislation has been adopted in some regions such as in Europe and in some states in the US, but by far not in all countries and thus no binding international agreement is in place (World Bank, 2018). With the introduction of the European Union Emissions Trading System (EU ETS) and a series of other measures to support the use of low carbon technologies such as renewable energy, the European Union (EU) is seen as a global leader in climate change policy (Naegele & Zaklan, 2019). However, a unilateral set of geographically limited policies raises production costs for domestic producers that threaten the international competitiveness of Europe-located companies with producers from unregulated regions, especially in carbon and energy intensive industries (Naegele & Zaklan, 2019). Facing relative competitiveness in an open world economy, this asymmetry has raised concerns of carbon leakage, meaning the relocation of CO_2 emissions and therefore production sites and labour from a region with environmental stringency into an unregulated area with less stringent environment policies (Dechezleprêtre, Martin, Gennaioli, Muûls, & Stoerk, 2019). This event is also known as the *pollution heaven hypothesis*. The shift of economic activities to less regulated areas implies that the policy is not only ineffective in respect to climate change goals which depends on total global emissions as emissions are likely to be relocate with production rather than being reduced, but also costly since employment and economic activity in the more regulated countries would be destroyed (Naegele & Zaklan, 2019).

The relocation of CO_2 emissions has been a topic widely discussed in both academical and political sphere. Especially in manufacturing sectors, the issue gains more and more importance since these sectors are very much likely to be affected by emissions as they often produce goods that are carbon intensive and massively traded on international markets (Dechezleprêtre, Martin, Gennaioli, Muûls, & Stoerk, 2019). In order to prevent carbon leakage, the most common used method so far is either to compensate or to exempt industries that are considered to be most unfavourably impacted by environmental policies. In the course of that, difficulties in establishing criteria for the allocation of adequate allowances to regulated companies have been arisen. Due to information asymmetry between regulator and regulated company, companies have the incentive to exaggerate their compliance costs to obtain more permits than they actually need to cover their emissions, which leads to overcompensation. This rent seeking behaviour leads to a boost of profits by selling the additional permits allowances on so-called secondary markets.

So far, the European Commission (EC) grants exemptions based on two simple criteria, carbon intensity of value added and trade exposure (Martin, Muûls, de Preux, & Wagner, 2014a). While recent studies provide important insights into the ETS system and its potential economic impacts, they rely mainly on the impact of these two criteria. Besides the controversial debate whether trade and carbon intensity are being sufficient in order to determine the eligibility for compensation, it is still not known, which other factors impact the decisions of relocation. Ahlvik and Liski (2019) empathizes that, depending on the industry, a correlation between abatement and relocation costs might exists, based on the occurrence that unilateral polices mostly include two distinct prices, a higher local price for firms that stay, and a lower global price for firms that relocate (Ahlvik & Liski, 2019).

In case of the existence of such a correlation, it is not a priori clear if the sign is positive or negative. To achieve the optimal policy design that allocates free permits in the most efficient way, it is indispensable to know the strength and the sign of the correlation as it would give an idea of *who* would leave the EU ETS first.

To my knowledge, the pollution heaven hypothesis has not yet been fully assessed empirically under the EU ETS. Martin, Muûls, de Preux, & Wagner (2014a) discover that relocation risk is limited, since they find out that carbon intensity is correlated with leakage risk, but overall trade exposure is not. They conclude that the current EC exemption criteria leads to a largely overcompensation of many sectors although a small risk of relocation exists. The research of Dechezleprêtre et al., (2019) addresses relocation channels, as they examine the risk of relocation of emission intensive processes within multinational firms. But no indication of relocation was found. Another research area focusses on trade flows: Ederington et al., (2005) are pointing out that pollution-intensive industries are considered to be less geographically mobile, or “footloose,” than other industries, since transport costs are high and therefore those industries are relatively more protected from foreign competition. The authors reveal that least footloose companies are those that have the largest emission reductions, suggesting a positive correlation between relocation costs and abatement costs. Nevertheless, those findings are based on US manufacturing and trade data. Some studies focus more on specific industries such as Sartor (2013), who finds no evidence that environmental stringency under the EU ETS would cause carbon leakage in the Aluminium sector and Branger et al., (2016) could not find carbon leakage in the Cement and Steel sector.

However, these findings still lack validity and explanatory power, since even though no evidence for carbon leakage was found, an explanation why was not given. In addition, managerial implications at a company level are missing in former research. This thesis aims to close this knowledge gap. From the current perspective, no analysis of the abatement cost on relocation risks of companies exists. The examination of a possible correlation between abatement costs and relocation risks is of importance as companies that reduce emissions under the EU ETS would relocate their production site abroad facing less stringent environmental policies could raise their emissions again. This would show how harmful firm relocations are for climate goals. To shed light on this problem, a unique data set is analysed: First, the impact of the EU ETS on relocation risk by using firm level data is assessed, which complements former studies focusing on relocation such as Martin et al. (2014a) and Dechezleprêtre et al., (2019). Second, emission trading data from different industries is used to classify sectors in pollution intensive and cutting emission categories in order to overcome the information asymmetry between regulator and regulated. Third these two data sets are combined, and the impact of abatement costs on relocation risk is examined. Yet, no previous research has analyzed unique interview-based data in order to predict the correlation between abatement costs and relocation risks, as far as I know.

1.2 Research Question and Outline

Based on the previous section, the general research question that this thesis aims to answer is the following:

Is there correlation between abatement costs and relocation risk across different industries ("footloose" vs. "non -footloose") under the EU ETS Scheme and if yes, which sign has it?

The remainder of the thesis is set out as follows: The thesis starts by providing a general theoretical basis of the economic model of emission trading by outlining both the theoretical framework and the institutional and political background, including system design and main parameters of the EU ETS. In section 3, a review of the previous literature is provided. Section 4 describes the data collection process in respect to abatements costs and relocations risk. Additionally, an overview of descriptive statistics is given, followed by a description of the empirical strategy in section 5. Afterwards the results of the analysis are presented in section 6, including several robustness checks. In section 7 the results of the model and possible shortcomings of the estimation strategy as well as of the data set are analyzed and discussed. Furthermore, the discussion introduces possible theoretical and managerial implications to provide an overview on how findings can be generalized and applied. The work is rounded off by a conclusion in section 8.

2. Theory and a brief Practical Overview

First, in subsection 2.1 the general principles underlying emissions trading and the issuance of emission certificates will be described. Also, a brief description of the mechanism of emissions trading on a secondary market will follow. Second, the theoretical framework of an emissions trading system is abstractly depicted (see subsection 2.2). Third, a short description is given on how the EU ETS cap-and-trade model using the economic model has been implemented. A brief historical review of the EU ETS will also be given, followed by a description of the allocation mechanism of allowances under the EU ETS (subsection 2.3). Fourth, an overview of sectors that are exposed to carbon leakage will be included in this chapter.

2.1 General Principles

Basic economic model of emission trading

Emissions trading is a market-based instrument. It represents a quantity-oriented control mechanism that is theoretically expected to reduce CO_2 emissions. A regulatory authority sets a reduction target for predefined and agreed upon emissions of CO_2. It then assigns capped permissions or certificates to the entities to be supervised, based on the overall reduction target of CO_2. Thus, by defining a total amount of assignable certificates, a hitherto non-existent limitation on pollution possibilities is set. By the same token a carbon dioxide emissions trading market is created, at which emissions rights are freely traded. Based on supply and demand of the abovementioned assigned and traded certificates, prices will be set or adjusted, rise or fall. Each player taking part in the emissions trading system is restricted to an emission output regulated by the emissions rights accorded to him (Nordhaus, 2007).

Issuance of emission certificates

Once the overall target of CO_2 emissions has been defined, it must be politically decided in which form the first certificate issuance takes place. There are two forms chosen for an initial allocation: a) The property rights are awarded by the state to the receiver of certificates by means of an assignment key, either output based or by grandfathering, and allocated to the receiver free of charge, or b) the rights are initially held by the state and are sold or auctioned to acquirers. The two allocation approaches (output based and grandfathering) have very different effects on competitiveness and emission reduction. Policymakers need to recognize to what extent different allocation approaches can change the impact of emissions trading, and thus adopt appropriate measures (Demailly & Quirion, 2006). A more detailed description of the mechanism behind the issuance of emission certificates under the EU ETS is following in chapter "Initial allocation mechanism of allowances under the EU ETS". The issued certificates may be traded by the players in a secondary market following the initial allocation in both abovementioned cases.

Secondary market

In a frictionless secondary market, the interplay of supply and demand should result in a single market price for emission allowances. The price of certificates has a steering effect for the individual market players, since they include the costs of the emission rights in their decision-making process: market participants are thus faced with the decision either to acquire emission allowances on the secondary market if they have not gotten enough certificates allocated at the initial allocation, or, in case they have acquired enough, to hold them as a pretext to emit CO_2, or to implement emission reduction measures in order to avoid acquiring emission rights. How the market participants decide depends largely on the costs (abatement costs) associated with the emission reduction versus set prices of allocated or traded emission rights (Amelung, 2014).

Rational actors reduce their emissions independently as long as their abatement costs are below the market price for pollution rights. In the optimization calculus, the marginal abatement costs of the last reduced emission correspond to the price for emission rights on the secondary market. This adaptation results in the individual emissions and thus the required quantity of certificates. Actors with relatively low-cost emission avoidance options and surplus emission allowances can sell certificates to market participants who have relatively high abatement costs. Those in turn prefer the purchase of certificates to their own cost-intensive avoidance of emissions. If all market players orient themselves to the price of pollution rights, not only the most favourable abatement options are implemented in the individual companies, but the socially cheapest emission reduction measures are carried out by trading the pollution rights.

The equilibrium price in emissions trading can thus be understood as a scarcity indicator for pollution potential or intention within the political guidelines. A low certificate price reflects the fact that high numbers of pollution rights or many relatively low-emission options are available on the market. It should be noted that the scarcity in emissions trading systems - unlike other markets - is a function of the politically determined quantities. What happens if the number of allowances is reduced, is illustrated in the following paragraph.

Pollution Permits

Figures 1a illustrates how the prices of tradable permits increase (from P_1 to P_2) if pollution restrictions cannot be met, thus increasing the demand (D) for “pollution certificates”.

(a) Fixed quantity of pollution permits (b) Decrease quantity of pollution permits

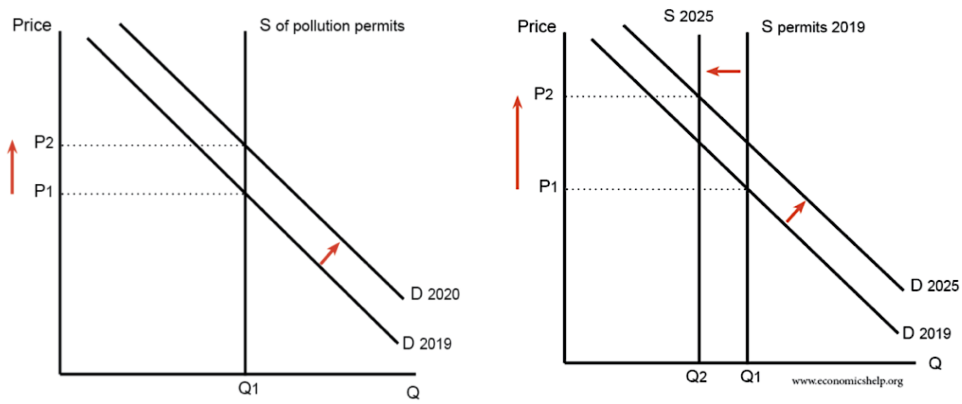

Figure 1: The interaction between quantity, price and demand of pollution permits, if (a) the fixed quantity of pollution permits stays the same over time, (b) the quantity of pollution permits decreases over time (economicshelp.org, 2019).

Nonetheless, the EU wants to meet its preset climate target which is a 20% cut in Greenhouse Gas (GHG) emissions (from 1990 levels) by 2020 and does so by reducing the issuance of certificates (up to 30% by 2020 (Table 1), diagramed in Figure 1b. Consequently, the price of allowances will steadily increase and therefore the EU hopes to generate a growing incentive to reduce pollution over time in its domain of influence, anticipating that companies will invest in new, environmentally cleaner, technologies.

However, if companies do not invest in the implementation of new technologies they need to keep paying the permit price which is expensive too. Therefore, companies have the option of relocating their production to countries that have less stringent environmental regulations. The possibility that multinational companies are swarming abroad to benefit from lax environmental standards is called the *pollution heaven hypothesis*. It states that environmental legislation will displace polluting activities for tradable products to poorer countries (Eskeland & Harrison, 2003).

Nevertheless, relocation doesn't only come with benefits from less stringent environmental standards. If the current location was chosen to keep transportation costs to a minimum level, it would imply that relocation leads to additional transportation costs, additional CO_2 emissions and efficiency losses (Næss-Schmidt, Bo Hansen, & Sand Kirk, 2011). For that reason, the actual decisions of a company to relocate depends on a number of different factors that are industry specific and should considered if assessing relocation risk. Drivers that influence the choice of relocation are described in more detail in the literature review and at the end in the course of the discussion.

2.2 Theoretical Frameworks

The following paragraph describes a simple case consisting of two firms Firm 1 and Firm 2. The overall or aggregated abatement costs between the two CO_2 emitting companies are minimized in order to achieve a target (Q*) of CO_2 reduction by means of allowances trading (emissions trading).

The principle of emissions trading is illustrated below for the two regulated companies, Firm 1 and Firm 2 (Figure 2). On the horizontal axis the quantities of abated CO_2 emissions by each of the two entities are represented, respectively Q_1 and Q_2. Quantity Q* is the emission target that must be met by each of the two companies at or during a defined time (otherwise there are penalties to be paid to the regulator). The aggregated reduction target is $2 \times Q^*$. On the vertical axis the Marginal Abatement Costs (MAC) for each of the two firms and the market price P at any one time for certificates are referenced. The two straight lines in the diagram, MAC_1 and MAC_2, indicate the MAC curves for Firm 1 and Firm 2, respectively. Firm 1 has steeper MAC than Firm 2, as the slope of MAC_1 implies.

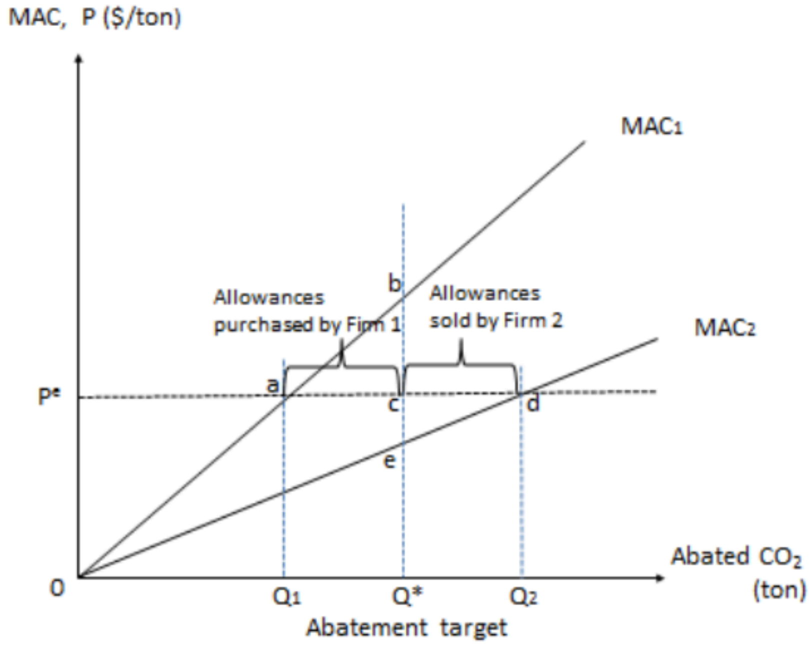

Figure 2: Basic Economic Model of Emission Trading

Note: The Figure 2 illustrates the allowances purchased by Firms 1 and the allowances sold by Firm 2 in order to meet the target Q*. Illustration extracted from Imai (2012).

Both firms decide how much emission of CO_2 to avoid by considering their current level of abated CO_2, the amount of their reduction targets, their MAC curves and the market price of allowances. For instance, if a firm´s MACs for an additional amount of abated CO_2 are higher than the market price for allowances and at the same time its current amount of reduced CO_2 is less than the agreed reduction target, the firm may buy certificates instead of reducing CO_2 during production. This may save abatement costs to achieve the reduction target. As Fig. 2 shows, Firm 1 reduces CO_2 emissions up to Q_1 by own means. But it must additionally purchase certificates from Firm 2 to make up for the not abated CO_2 emissions that would have allowed it to satisfy the agreed upon abatement target Q*.

In the event of its MAC is lower than the actual market price for allowances, also with an additional amount of CO_2 emission avoided, if the said avoided or abated emission are above the reduction target, the firm may decide to sell this surplus as certificates, as it is then possible to generate profits. As depicted in Figure 2, Firm 2 reduces CO_2 emissions, surpassing the objective of the preassigned target Q* and sells the surplus of its allowances to Firm 1.

The illustration shows that the market price for allowances is at P^e, where the quantities of purchased allowances for Firm 1 (Q* - Q1) and those sold by Firm 2 (Q2 - Q*) are equal (one unit of allowance equals one ton of CO_2). If the following equations (1) and (2), below, are fulfilled, the aggregated reduction target (2 × Q *) is achieved at minimized costs P^e (Imai, 2012):

(1) $P^e = MAC_1 = MAC_2$

(2) $(Q_1 - Q^*) + (Q_2 - Q^*) = 0$ at P^e

Note: MAC_1, MAC_2, and Q* are given. Equation extracted from Imai (2012).

This basic economic model of emissions trading for the simple case of two companies shows that emission trading can minimize the overall costs of reducing CO_2 emissions to achieve an aggregate emission reduction target (2 × Q*). The aggregate abatement costs achieved by emissions trading is calculated by summing the triangle areas: $0aQ_1 + 0dQ_2$. This is equivalent to 0acQ* + 0eQ* - cde (see Figure 3). Without emissions trading, the aggregated reduction costs would then amount to the sum of the following areas: 0bQ* + 0eQ*.

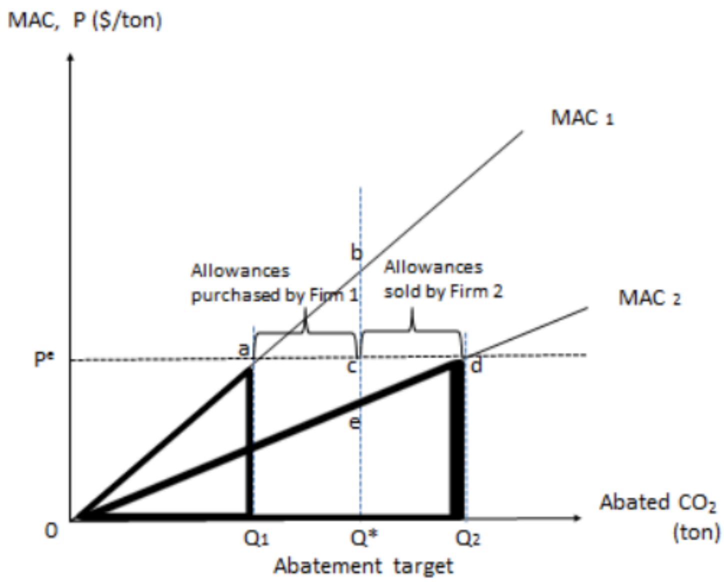

Figure 3: Aggregate Abatement Costs in Emissions Trading

Note: Figure 3 shows graphically the decreased aggregate abatements costs by emissions trading that consist of costs that firms saving if they are purchasing allowances and of profits for the firms that are selling these allowances. Illustration extracted from Imai (2012).

In addition, the reduced abatement costs consist of two components: cost savings and profits.

These reduced abatement costs are obtained by summing the triangles abc + ace = abc + cde (see Figure 4). A firm with a relatively steep MAC curve can minimize its abatement costs through emissions trading. The saved reduction costs are shown by the area abc. It can be obtained by subtracting the purchasing costs of certificates (area acQ* Q_1) from the area abQ* Q_1. A firm with a gently inclined MAC curve can achieve profits through emission trading. This profit is represented by the area cde. It can be derived by subtracting the revenues from the sale of allowances (area cd Q_2Q* - area ed Q_2Q*) (Imai, 2012).

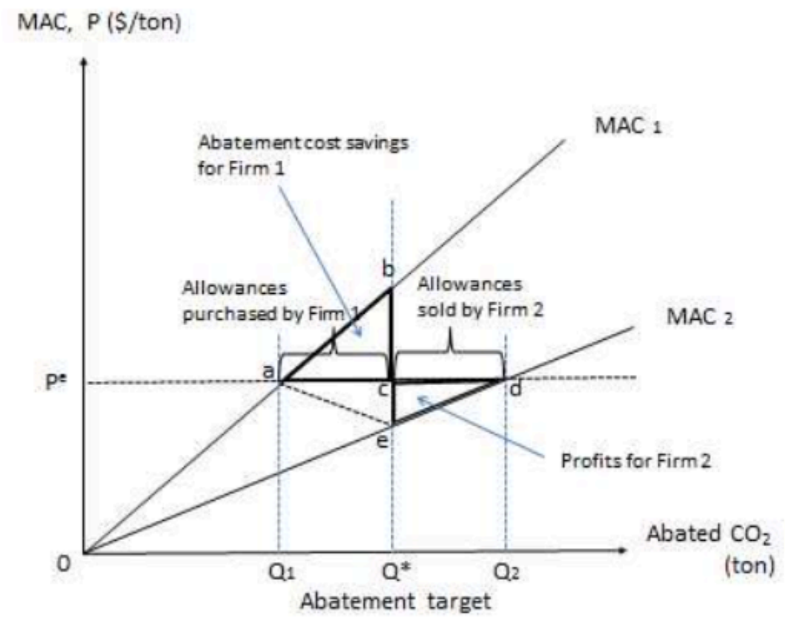

Figure 4: Abatement Cost Savings and Profits from Emissions Trading

Note: Figure 4 displays actually the same as Figure 1 besides that the abatement cost that Firm 1 is saving and the profits for Firm 2 are implicated by the areas with bold lines. Illustration extracted from Imai (2012).

Extension of the basic emission trade model to more than two firms

The basic economic model of emissions trading for the case of two entities evaluate in the previous section shows that emissions trading can minimize aggregate reduction costs to achieve the aggregated reduction target. The question that now arises: *How do the graphic change if we include in the model more than to two firms*? (Note: The EU- ETS operates in 31 countries)

Graphically, this could be easily illustrated by plotting the MAC curves of all companies involved in Figure 2. The two conditions at an equilibrium price for permissions, Eq. 1 and Eq. 2 in the previous section can be considered the following Eq. 3 and Eq. 4. If both of Eq. 3 and Eq. 4 are satisfied, the aggregate reduction target (n × Q*) is achieved at least cost:

$P^e = MAC_1 = MAC_2 = \ldots = MAC_i$

(3) i = firm 1, 2, …, n

$(Q_1 - Q^*) + (Q_2 - Q^*) + \ldots + (Q_i - Q^*) = 0$

(4) at P^e i = firm 1, 2, ……n

where MAC_i and Q^* are given.

Note: Equation extracted from Imai (2012)

Since the EU- ETS operates in 31 countries and covers around 45% of the EU´s GHG emissions and limits emissions from around 11,000 heavy energy-using installations, the expanded model the extended model is closer to reality (European Commission, 2019a).

Price stabilization mechanism

The existing emissions trading systems have different design options for a price stabilization mechanism (Amelung, 2014). Since the total amount of emission rights is fixated within a cap-and-trade system, the initial rights allocation is price-inelastic. As a result, the supply of those rights is not affected by adjusting the quantity to an increased demand. High cost burden can however lead to a decrease in acceptance of emission trading. In addition, high prices for emission allowances induce emigration tendencies of industries and thus engender so called carbon leakages. For the purposes of this thesis, carbon leakage and relocation are considered equal only if a positive correlation can be found between companies that reduce emissions and relocation risk. In turn, a minimum price for emission allowances facilitates planning certainty at companies investing in low-emission technologies. Furthermore, many emissions trading schemes aim at creating long-term investment incentives, though they may be accompanied by relatively high costs. Reduction of greenhouse gases at lower than originally expected costs justifies fixing a minimum price. Finally, it can be concluded from the known economic models, that the final allocation of permits does not depend on their initial supply. Therefore, the resulting price itself is not affected by the original distribution of permits, since the original allocation does not affect the marginal cost function of the companies (Hahn & Stavins, 2011).

Emission Trading in connection with Carbon Leakage

In order to prevent carbon leakage, it is indispensable to find out which price and which quantity of free allowances appropriate. For this it is essential to define which industries reduce CO_2 emissions and thus sell certificates and which industries do not reduce CO_2 and thus buy certificates. Since climate change is a global problem, the aim is to prevent the latter from leaving the EU ETS to pollute in countries with less strict environmental policies. Instead, incentives should be created to implement technologies. The economic mechanism behind carbon leakage is illustrated in the following figure:

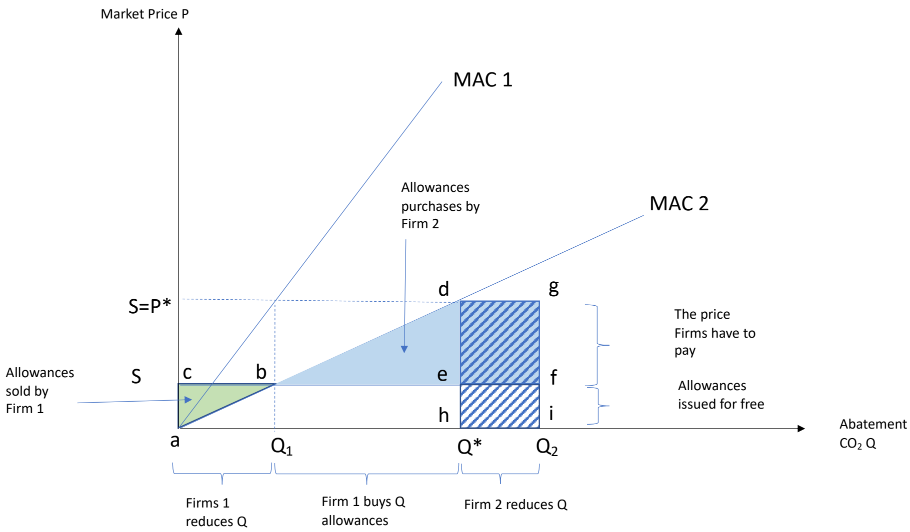

Figure 5: Carbon Leakage as a result from emission trading

Note: Illustration generated by the author of this thesis.

In the case that only a part of the certificates will be issued for free, the free allowances can be seen as a subsidy. Those free allowances can be sold on the secondary market to firms that pollute too much and are not reducing enough CO_2 by themselves. In this case, Firm 1 is reducing up to Q_1 CO_2 by itself and is able to sell this number of free permits to Firm 2 abc-area. Firm 2 reduces CO_2 emissions above the reduction target Q* and sells the surplus of its allowances to Firm 1 (area dghi). But Firm 2 has still to pay the price for the certificates that is displayed in the bde- area. According to the leakage risk hypothesis, companies will relocate their production sites, if the price the companies have to pay for those certificates (area bde) rise up to a point that corresponds to the level of their outside option.

2.3 A Cap-and-Trade System - The EU ETS

This section gives a short description of how the previously described economic principle of emissions trading is implemented in practice using the European Union Emissions Trading System (EU ETS; an institutionalized cap-and-trade system).

Overview

The EU ETS limits the total GHG emissions of European countries by means of reduction of emitted CO_2 as a measure of global warming potential. The cap assessment determines the number of certificates available in the system. The ceiling is set to decrease annually from 2013 and reduce the number of allowances for companies covered by the EU ETS by 1.74% per year. As a result, companies can slowly adjust to the increasingly ambitious overall emissions reduction target. Each year, some of the allowances are given to certain subscribers free of charge, for example in sectors where there is a potential risk for carbon leakage (refer to section 2.2.3 for a definition of vulnerable sectors). If an entrant does not have enough entitlements, it must either reduce its emissions or buy more allowances on the so-called secondary market, where companies that have a surplus of allowances are offering and selling those. Participants that are short of certificates can purchase allowances at auctions or from other companies that have a surplus, as demonstrated by the Figure 6 (European Commission, 2015). Those allowances have a value since the entire number of certificates is limited and therefore there is a demand by those participants for which the costs of reductions are higher and a supply by those for which the costs related to reducing CO_2 emissions are lower.

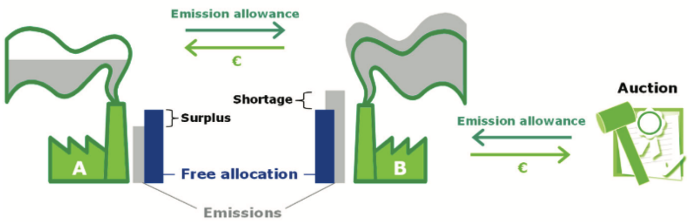

Figure 6: Mechanism behind the cap and trade system under the EU- ETS

Note: Illustration extracted from European Commission (2015).

Those allowances have a value since the entire number of certificates is limited and therefore there is a demand by those participants for which the cost of reductions is higher and a supply by those ones for which the reduction of CO_2 emissions is lower. The EU ETS is now in the so-called third phase and it is planned that in 2020, emissions from sectors covered by the system will be 21% lower than in 2005 (European Commission, 2019a).

2.3.1 The EU ETS – A historical review

The Kyoto Protocol of 1997 established legally binding emission reduction targets for 37 industrialized countries for the first time. As a result, policy instruments were needed to achieve these goals and therefore in March 2000, the EC presented a so-called green paper with initial ideas on the design of the EU ETS. The implementation of the system has been subdivided over time into various trading phase, that are shown by Figure 7. The EU ETS operates in 31 countries and covers around 45 % of the EU´s GHG emissions and limits emissions from around 11,000 heavy energy-consuming installations (European Commission, 2019a)

Figure 7: Timeline EU Emission Trading System

Note: Illustration extracted from European Commission (2015).

Phase I & II. In Phases I and II, the allocation of permits was regulated by the National Allocation Plan (NAP), which means that each member state has developed a NAP that determined the national cap and fixed the permit allocation at sector level. Phase I can be regarded as a three years pilot learning-by-doing phase in order to prepare for the second phase, where the EU ETS had to operatively meet the Kyoto target. Most of the countries went in Phase I under a grandfathering (GF) clause, by which the number of free allowances allocated to the firms, independently of their current line of action, is based on historical emission records (Martin, Muûls et al., 2014b). Phase II corresponds to the first commitment period of the Kyoto Protocol, at which time countries in the EU ETS had to meet concretized emission reduction targets. With verifiable annual emission data obtained from Phase I (pilot phase), thus based on actual emissions at the time, the cap on allowances in Phase II had been reduced. The main contribution of Phase II was the establishment of a “lower upper limit” for certificates (about 6.5% lower than in 2005).

Phase III. With the beginning of Phase III (2013-2020), the rights to allocate allowances has been taken from national governments and given to Brussels. Based on the amended Emissions Trading Directive 2009/29/EC6 the allocation of emissions allowances is shifted to full auctioning as a basic principle. A harmonized allocation scheme is thus put in place as a means of reducing distortions from competition between producers of similar products in the Member States. The two main features underlying the auctioning scheme are (1) the use of benchmarks derived from the operators who have taken early action to reduce the emission intensity of production, (2) the continuance of allocation of free emission permits to sectors that are at risk of CO_2 carbon leakage (Martin, Muûls et al., 2014b). A more detailed definition of carbon leakage is given in section 2.2.3. According to the European Commission 57% of the total amount of allowances will be auctioned. The then remaining allowances are available for free allocation over the current trading period of Phase III (2013-2020) (European Commission, 2019a).
Additionally, gradual transition to full auctioning is achieved by introducing scaling factors, already defined in the original Emissions Trading Directive 2003/87/EC (Martin, et al., 2014b), assuming values from 0.8 in 2013 to 0.3 in 2020. By entering Phase III, free allocation for electricity production are for the first time excluded.

Moreover, the EC postponed the auctioning of 900 million allowances until 2019-2020 as a short- term shortage, as a result of which the price should increase in the short term. The EC reacts to the low issue price of 4-7 euros, or to an accumulated surplus of 2.1 billion allowances. From the point of view of the political actors, this price set too low a level of investment in low-emission technologies. The overall number of allowances that are auctioned during Phase III is not reduced by this back loading of auction volumes, but it only decreases the distribution of auction over the period of Phase III. Back loading can rebalance supply and demand and therefore reduces price volatility without having any significant effect on competitiveness (European Commission, 2019b).

Preparing for Phase IV. The proposal for Phase IV matches the political agreement of the European Council of October 2014 to decrease domestic GHG emissions by at least 40% by 2030. To contribute to the goal of reducing greenhouse gas emissions by 2030, the sectors covered by the EU ETS need to reduce their emissions by 43% compared to 2005 levels. Therefore, the total number of emission allowances will decrease with an annual rate of 2.2 % from 2021, compared with 1.74% in the third phase (2013-2020). Furthermore, it is intended with the reduction of emission certificates to strengthen the market stability reserve. This is a mechanism that was set up by the EU in 2015 to reduce the oversupply of emission allowances on the carbon market and increase the resilience of the EU ETS to future turbulence. It displays a long-term solution and a will start operating in January 2019. As a consequence, the 900 million allowances that were back-loaded in Phase III will be transferred to the reserve rather than auctioned in 2019-2020. Should the surplus of emission rights continue to be large in future, certificates will be held back in auctions and transferred to a reserve. If the surplus of emission allowances then falls below a predetermined level, the reserve will be dissolved again through additional auctions, which will lower the market price again (Amelung, 2014).

2.3.2 Initial Allocation mechanism of allowances under the EU ETS

Considering the allocation of free allowances, various questions arise in this context: *Which sectors are getting the permission to emit greenhouse gases? To whom are the emission rights legitimized?* Since the emission rights can be sold on the secondary market, they have a currency equivalent - regardless of who receives them first. There is no clear scientific answer to those normative questions, such as to whom this newly created value of the certificates should be awarded. In principle, a distinction is made between two basic positions, which are reflected in the allocation mechanisms used:

a) The emission credits are awarded to the issuers. This is done by issuing the certificates free of charge to the issuers by means of an administrative allotment rule. The allocation rule is mainly based either on historical corporate emissions data (grandfathering method) or on technical specifications of the plants (benchmark method)
b) The property rights belong first to the political authority, which represents the interests of the citizens. The former will either auction the certificates or sell them to the issuers at a price set by the administration. This initial allotment by auctioning or sale is also referred to as the primary market as opposed to the secondary market (see also section 2.1 - secondary market) for emission allowances (Amelung, 2014)

Emission allowances can be allocated not only by quota but also in terms of efficiency. High transaction costs incurred within secondary market trading, poor market information due to fewer transactions, also international competition, to which some industries are usually exposed, can justify a distribution of free emission rights (Amelung, 2014).

2.3.3 Carbon Leakage under the EU ETS

In general, CO_2 leakage can be defined as the relocation of economic activity and/or changes in investment patterns that directly or indirectly result in emissions from a territory with GHG restrictions being moved to another jurisdiction, with or without restrictions (Marcu, Egenhofer, Roth, & Stoefs, 2013). In certain energy-intensive industries, the risk of carbon leakage can be higher (European Commission, 2015). An ambitious climate policy that implement higher pollution related costs might put sectors in the EU at a competitive advantage compared to those that are not facing similar costs such as Cement or Iron & Steel manufacturing. The shift in CO_2 emissions could therefore undermine environmental integrity and the benefits of emission reduction measures in Europe. Under the EU Emissions Trading Scheme, industrial plants that are at significant risk of carbon leakage are treated separately to support their competitiveness (European Commission, 2015). This special treatment means that those sectors that are facing carbon leakage receive 100% of their allowances up to a certain benchmark for free. On the contrary, sectors that are not considered to be exposed to carbon leakage receive an 80% share of their allowances for free in 2013 and this share will decrease to 30% by 2020 (European Commission, 2015). To penalized operating leakage, that is if a company shuts down productions' sides, all freely allocated emission allowances are cancels in case a regulated facility closes (Martin et al, 2014b).

Table 1: Gradual Decrease in Allocation of Free Allowances from 2013 to 2020

Share of free allocation calculated based on benchmarks per sector	2013	2014	2015	2016	2017	2018	2019	2020
Electricity production	0%	0%	0%	0%	0%	0%	0%	0%
Industry sectors	80%	72.9%	65.7%	58.6%	51.4%	44.2%	37.1%	30%
Industry sectors deemed exposed to carbon leakage	100%	100%	100%	100%	100%	100%	100%	100%

Note: Table extracted from European Commission (2015).

The above table illustrates in Phase III the gradual decrease in the proportion of allowances granted free of charge over the years to industries not endangered by carbon leakage.

Electricity production is excluded from free allowances. Industry sectors that are exposed to carbon leakage get 100% of emission allowances free of costs (European Commission, 2015).

Criteria and vulnerable sectors

The EU has also released a list consisting of sectors and subsectors that are considered to be at significant carbon leakage risk. According to the ETS Directive (Article 10a), it is assumed that a sector or sub-sector is exposed to a significant risk of carbon leakage if: (a) the sum of the direct and indirect additional costs caused by the implementation of the Directive would result in a significant increase in production costs, measured as a percentage of Gross Value Added (GVA), of at least 5%, and (b) the intensity of trade with third countries (imports and exports) exceeds 10%. A sector or sub-sector is also considered to be exposed to such risk even if the sum of direct and indirect additional costs is at least 30% or the intensity of trade with third countries exceeds 30%. Investments in sectors exposed to significant carbon leakage risk can in principle receive 100% of that amount of free allowances. For investments in other sectors that are not included in the carbon leakage list, the free allocation in stages will be progressively reduced (annual reduction from 80% in 2013 to 30% in 2020).

Among the most frequently cited sectors and products that may pose a risk of carbon leakage are Cement, aluminum, Iron and Steel, Paper, Refineries and Chemicals. The selection of sector plotted by trade exposure and total ETS costs/GVA is displayed in Figure A1 in the Appendix. The criteria most commonly used to assess the risk of CO_2 leakage are the relative importance of carbon and trade intensity. The European Commission uses the two criteria to assess carbon leakage risk: (1) Impact assessment of ETS costs in terms of GVA and (2) trade risk (Marcu, Egenhofer, Roth, & Stoefs, 2013).

However, research can be found that explicitly states that there are too many sectors on the list that are assumed to be affected by carbon leakage, because inappropriate choice of indicators and or too low thresholds (e.g. the trade intensity indicator is set too low) in the assessment (Dröge, 2009). Also, Martin et. al. (2014b) found a large potential for improving the efficiency of compensation in order to avoid leakage, even if those improvements are based on simple criteria such as firm level employment or carbon emissions. Furthermore, they point out that the EC compensates polluting intensive industries too generously at the expense of European taxpayers. In the course of their assessment of carbon leakage sectors, they found out that most of the sectors that are considered by the EC at risk of carbon leakage are not carbon intensive at all. Other implications that can be considered additionally as categories of trade and carbon are discussed in more detail in the next chapter.

3. Related Literature

The degree to which carbon leakage took place as a response to the EU ETS so far, or is likely to take place, has been investigated in a range of studies. The following subsections deal with previously named research on the pollution abatement costs of different industries and with the relocation costs/risks of those industries. The subsections 3.1 and 3.2 of this chapter review studies with reference to carbon leakage. Subsection 3.3 relates to studies that analyze the abatement costs regarding different industries as well as different allocation approaches. Subsection 3.4 provides an overview of studies that relate to relocation risks. In subsection 3.5, the implications for this study are specified. The chapter concludes with the presentation of the expected effects of abatement costs on relocation risks. Since the literature examined does not explicitly correlate abatement costs and relocation risks, subsection (3.6) will step in. Two hypotheses regarding correlations will then be formulated and examined in this work.

3.1 The Carbon Leakage Criteria Re-Examined

This thesis leans strongly on Martin et al. (2014b). Regarding carbon leakage risks, their analysis based on managers' responses bear similar results to the EC carbon leakage criterion ((European Commission, 2009c), refer also section 2.2.3) and confirms that carbon emission intensity is a good indicator of leakage risk, the level of trade not so much. The latter criterion is in line with other researchers' findings, where disparate applications of the trade intensity criterion by different countries make it an unsatisfactory measure of forecasting carbon dioxide avoidance costs, therefore do not provide enough ground for assessing the risks of CO_2 leakage (Sato et al. 2015).

Moreover, Martin et al. (2014b) have suggested two modifications to the EC carbon leakage criteria. They recommend including trade intensive (TI) industries only if they are also CO_2 intensive (CI). A second proposal aims at the adoption of a more specific TI measure, applied to commerce with less developed countries. Numerous non-EU countries are excluded from the application of the TI measure, although it is likely that this mismatch may lead to overly generous compensations in form of free permits issued to trade-endangered industries for which there is no relocation risk due to CO_2 prices. Their analysis classifies sectors or subsectors prone to carbon leakage, using trade, carbon and electricity intensities as proxies for the effect of the EU ETS on competitiveness.

In this context, CI represents the costs of full auctioning and is calculated as the sum of the direct and indirect costs of auctioning permits divided by gross value added of a sector (European Commission, 2015). At this juncture direct costs are calculated as the value of direct CO_2 emissions (assuming a proxy price of €30/tCO_2). Indirect costs cover the risk of electricity price increases that are unavoidable due to the full auctioning of licenses in the electricity sector. The TI ratio is measured as the relation of the total value of exports to third countries and the value of imports from third countries and total market size for the European Economic Area, that means the annual turnover plus total imports from third countries. The following categories have been developed for sectors that have a significant risk of carbon shifting by Martin et al. (2014b):

- A- high carbon intensity (CI> 30%);
- B1- high trade intensity and low carbon intensity ($CI \leq 5\% \cap TI > 30\%$);
- B2- high trade intensity and moderate carbon intensity ($5\% < CI \leq 30\% \cap TI > 30\%$);
- C-moderate carbon and commercial intensities ($5\% < CI \leq 30\% \cap 10\% < TI \leq 30\%$).

The only difference in the classification of categories compared to those of the European Commission (2009) is that category B is divided into two subcategories by Martin et al. (2014b): subcategory B1, whereas CI is less than or equal to 5% and subcategory B2 where CI is lies between 5% and 30 %. However, the European Commission makes no further subdivision at carbon intensity under 30 %. The results of the classification are displayed in the Figure 8.

Martin, et al. (2014b) are also emphasize that the proportion of non-auctioned CO_2 emissions is only 15 % (excluding the energy sector), which leads to the fact that the Carbon Leakage Decision leaves most of the pollution rights to European industry, and thus the principle of full auctioning in the amended ETS Directive get strongly undermined. In addition, they pointed out that previous studies have shown that EU ETS has a negative impact on production in the most regulated industries while the increase of electricity prices affects the profitability of heavily exposed industries. These studies display that the free distribution of income can offset negative gains in most industries and even lead to overcompensation (Martin, et al., 2014b).

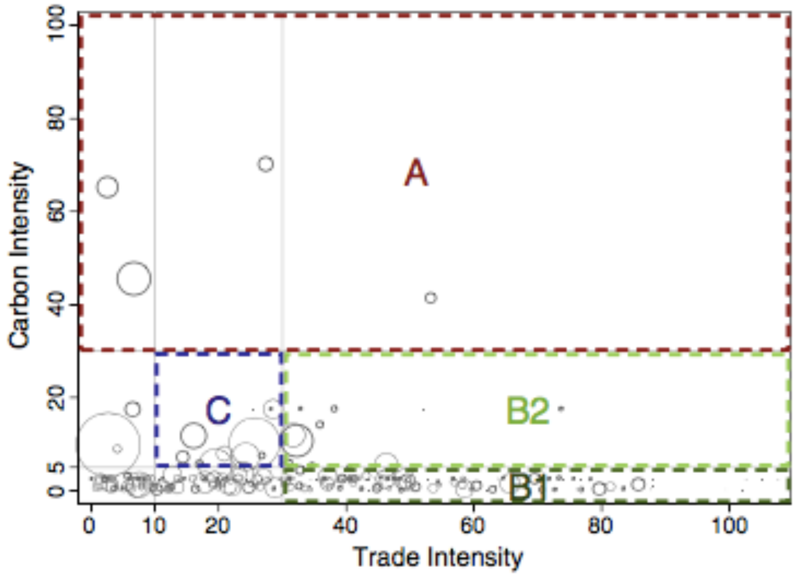

Figure 8: Schematic display of sectors exempted from permit auctions

Note: This figure shows the 4-digit sectors (NACE) that are exempt from permit auction in EU ETS in Phase III in a diagram with CI on the vertical and TI on the horizontal axis. The size of the bubble displays the number of firms in a given industry proportional. For all these measures the category B turns out to be the largest group of exempted companies, as Figure 8 illustrated. But it can be also seen that most of these sectors are not at all CO_2 -intensive (e.g. CI <5%). Illustration extracted from Martin et. al., (2014b).

However, Martin, et al., (2014b) concluded that the European Commission compensates polluting industries too generously, as most of the sectors being considered e at risk of carbon leakage by the EC are not carbon intensive at all, since their carbon intensity is less than 5%. Martin, et al. (2014b) suggesting simple improvements in order to improve the efficiencies of compensation offered to avoid carbon leakage based on the correlation between the level of relocation skid and carbon leakage criteria. But, especially with regard to the carbon leakage criteria, they rather focus on the amount of companies that would leave the EU ETS due to carbon leakage, but they do not explicitly define *who* exactly would leave.

Looking into further literature, it turned out that there are other important factors besides carbon and trade intensity, that determine whether a sector or a product is at carbon leakage risk and therefore define who these leaving companies could be. According to Marcu et al. (2013) factors that need to be considered when a sector is at risk of CO_2 leakage may include energy- intensive industries that are not producing direct CO_2 emissions but are still using energy that internalizes CO_2 costs or better the use of components or semi finish products that

internalize CO_2 costs. In addition, Marcu et al. (2013) propose that the importance/ratio of carbon costs compared to other variables should be considered if sectors are classified as carbon risk sectors.
Another category that is important in relation to carbon leakage is the reduction potential or the level of cost reduction in a given sector. It is assumed in this study that the amount of abatement costs of CO_2 in each sector has an effect on the relocation possibility of its productions site and thus, risking carbon leakage. One of the main reasons why the issuing of free certificates is reduced in phases under the cap and trade scheme is among others the acceleration of the development of emission reduction technologies. Therefore, endogenous technological change not only reduce emissions in the regulated sector but can also lead to spillover effects that reduce emissions in other sectors and countries (Di Maria & Smulders, 2005).

Furthermore, one category that needs to be further developed is the ability to endure the cost of CO_2. Marcu et al. (2013) are pointing out that CO_2 costs do not necessarily result in carbon leakage unless they are at a cost that affects competitiveness. In case that a sector is able to pass costs downstream or to customers, the risk of carbon leakage decreases or even disappear depending on the portion of pass-through. But on the other side, if costs cannot be passed through, for example due high level of international competition or global price mechanism, profit margin will be affected and so the risk of carbon leakage increases. Factors that affect the ability to pass through cost are versatile. Some of these are explicitly mentioned in the literature. These are, for example among others the exposure to international competition, market concentration, product differentiation, available substitutes that require less emissions or energy, transport costs in relation to the CO_2 costs, exchange rate risks, customer response to a price increase based on /vertical integration of the industry, quality problems and long-term contracts, Legal and political framework and global pricing mechanism (Marcu et al., 2013).

One factor that needs to be briefly highlighted here as a factor that has an effect on the ability to pass though the costs is the market structure of the EU ETS. The EU ETS, with 15% of the major emitters, accounts for 90% of total EU ETS emissions. The 90% are dominated by the electricity and heat sectors with around 73% of emissions. Consequently, the costs of CO_2 emissions are usually concentrated in a limited number of sectors, and the benefits are distributed both within and between the generations. Since asymmetric CO_2 restrictions and prices will fundamentally affect industrial competitiveness and the economy as a whole, certain sectors and products are influenced (Reinaud, 2008). Some previous research found out that emissions-intensive industries are responsible for 1% of UK Gross Domestic Product (GDP), and that they accounted for 2% of Germanys GDP (Hourcade, et al., 2007). As a consequence, depending on how high the emission's share in the GDP of a country is, sectors are affected differently even within Europe. This should be included in the assessment whether a sector is at carbon leakage risk or not (Marcu, et al., 2013).

Another example in the literature that shows that the market structure should be considered is the sector of electricity production in which the carbon intensity varies widely across Europe. It is assumed that in competitive national markets and with a 100% cost pass through rate, companies in countries with a high intensity of generation are expected to profit more from free allowance allocation than those with low carbon intensity such as Sweden and France that are characterized by almost no fossil systems. The opposite would be the case if electricity trading in the EU tends to increase prices. However, these effects are mitigated by regional differences in ownership structures, the degree of concentration in the market and the regulatory environment. For example, fixed retail prices, as in France, and contractual arrangements restrict the ability of companies to pass through the cost of CO_2 in electricity prices. These differences may explain why profits vary significantly between electricity companies in different countries (Sato, et al., 2007).

According to Sato, et al., (2007), the following three categories should be included on the qualitative side if a sector has a threshold values on a quantitative side, in order to decide whether a sector is at carbon leakage risk or not:

1) Emissions levels and electricity consumption reduction potential of individual installations in the sector
2) Current market characteristics and future trends
3) Profit margins as an indicator of long-term investment or relocation decisions

Nonetheless the availability of data on the pass-through of carbon costs criteria is rare and difficult to assess and therefore, this element (if any) is not always included in the assessment of carbon leakage.

3.2 Carbon Leakage under the EU ETS

In terms of carbon leakage, some ex post results that have been completed to date are briefly described in the following paragraph.

Most ex post studies indicate little or no carbon leakage, for example (Chan, Li, & Zhang, 2013) have pointed out that in case of cement, iron and steel there was no evidence of carbon leakage. This is confirmed by the work of Ellermann, et al. (2010), who also found no observed impact in the oil refining, cement, aluminum or steel sector. Anger & Oberndorfer (2008) do not find a significant correlation between the degree of overallocation of German firms and their revenues or employment. Kenber, et al. (2009) concluded that the introduction of the EU ETS does not appear to imply either significant costs or a fundamental change, such as the decision to relocate or to reduce workplaces. However, some of the studies contradict the above findings. Abrell et al. (2011) found that EU ETS has a small negative impact on employment but not values added or profit margin. Commins, et al. (2011) found, however, that EU ETS has a native impact on product viability and profits but not on employment.

In addition, the public debate and stakeholder comments do not immediately make it clear what effects are summarized under the term “carbon leakage”. Does the term “carbon leakage” means a loss of market share of an EU ETS facility to a non-EU competitor, lower level of investments made in the EU, the physical relocation of industrial facilities outside of the EU, or does it cover more than one or even all of these occurrences? (European Commission, 2015)

This summary of the previous literature and its results shows more than clearly how diversified the research results are. After a thorough evaluation of the already existing literature, the question arises whether carbon leakage is a serious problem or whether it is only inflated artificially. Currently, there is little empirical evidence on the effects of the Cap and Trade Scheme under EU ETS EU on the industrial sectors that are most exposed to the risk of CO_2 leakage.

3.3 Abatement Costs and Carbon Leakage

The Kyoto Protocol calls for a number of developed countries to limit their emissions, while other countries do not act: "Abatement activities of the industrialized countries might result in a movement of the GHG emissions into the regions with no restrict" (Paltsev, 2001). Therefore, it is very important to take abatement cost into account in terms of avoiding carbon leakage. Marginal Abatement Cost (MAC) curves are a widely used policy tool that indicates the potential for reducing emissions and associated mitigation costs. They have been used extensively in a number of countries for a range of environmental problems and have increasingly been used in climate policy (Kesicki & Strachan, 2011). One recent study on the reduction of greenhouse gas emissions was published by McKinsey & Company (2013) which produces a cost-effective greenhouse gas avoidance curve for various energy efficiency measures. The analysis shows that by 2030 it will be possible to reduce GHG emissions by 35% compared to 1990, or by 70% compared to 2030 if the world collectively barely seeks to contain current and future emissions. In terms of funding, the total upfront investment in the necessary mitigation measures in 2020 would be € 530 billion per year or € 810 billion per year by 2030, compared to business as usual (BAU) those investments would be incremental. Therefore, the necessary investments appear to be within the long-term capacity of global financial markets. Consequently, many of the possibilities would mean that future energy savings would largely offset upfront investment (McKinsey & Company, 2013).

However, considering the MAC with regard to energy efficiency, Kesicki & Strachan (2011) criticize that the avoidance potential can be significantly overestimated, since market barriers such as uncertainty and costs of implementation of technologies are not covered. Moreover, non-observance of international and intertemporal interactions can lead to marginal cost estimates and lead to biased policy assessment. Therefore, it is recommended that a MAC is not used as an exclusive decision support for the classification of emission reduction measures.

Furthermore, a study commissioned by McKinsey & Company (2007) that examined the costs and potentials of GHG prevention in Germany, found out that in industrial sectors, greenhouse gas emissions can be reduced both by continued increases in energy efficiency (for example, by more efficient propulsion systems and more specific industrial measures) and by the targeted interception of greenhouse gases (such as nitrous oxide in the chemical industry). Furthermore, they pointed out that the increasing use of efficient drive systems, including

mechanical system optimization, will make the largest contribution to avoiding emissions by 2020. The historical increase in energy efficiency in industry suggests that a significant part of these measures will be implemented in normal investment cycles without additional incentives.
However, some levers call for decision-makers' willingness to intervene in established processes, while ensuring process stability on an ongoing basis (McKinsey & Company, 2007). The potential and cost-effectiveness of these measures for individual industries depend heavily on the individual circumstances of the respective industries. In addition to the costs resulting directly from the implementation of the mitigation levers, it is particularly important for energy-intensive industries to incur additional costs due to the existing CO_2 regime and changes in fuel and electricity prices. Without integration into a global context, the implementation of these alternatives would lead to significant distortions of competition, for example in German companies. Most of the mitigation potentials explored in the study conducted by McKinsey & Company can only be realized through the use of well-known and proven technologies. However, especially after 2020, some technologies that are still in their early stages of development will be relevant from today's perspective. These include, in particular, CO_2 capture and storage technologies (CCS), power generation in offshore wind farms, and the introduction of second-generation biofuels (McKinsey & Company, 2007).

However, it should be noted that the isolated implementation of mitigation measures by CCS technologies in energy-intensive industries (such as Steel and Cement) would result in an immediate loss of international competitiveness. The implementation of CCS technologies in power generation alone would lead to a corresponding increase in electricity prices which will also hit energy-intensive industries, including high-power industries such as non-ferrous metals. These effects would significantly affect the competitiveness of the industries concerned, as long as they are not embedded in a global context (McKinsey & Company, 2007).

Another study focusing on greenhouse emissions has found out that the cost of mitigation varies according to geographic location, plant capacity, reduction measures implemented and initial CO_2 emissions. Even if the payback time of the investment’s changes, the savings in operating costs in most cases make the investment viable, especially if there are benefits to carbon trading (Kajaste & Hurme, 2016).

3.4 Relocation Risk

Previous studies are pointing out that US manufacturing and trade data notes that the least lint-free companies are those that have the largest emission reductions, suggesting a positive correlation between relocation costs and abatement costs (Ederington et al., 2005). They emphasize that an increase in environmental costs is likely to have different effects on different industry: “Some industries (because of high transport or relocation costs) may be insensitive to changing comparative advantage or changes in production cost, while other industries (the footloose industries) are more sensitive” (Ederington et al,.2005). The authors have defined three categories for describing immobility: geographic immobility: transport costs on product markets, fixed costs and agglomeration economies. They concluded that polluting industries seem relatively immobile. Furthermore, this incident leads to the assumption that a disregard of this finding may lead to the preposterous finding that polluting industries are less sensitive to rising environmental costs. In addition to the immobility of the industries, the authors have also eroded the intensity of trade. They concluded, in order to determine the impact of environmental legislation on industry, two main characteristics of an industry need to be considered (1) the level of trade with low-income countries and (2) the geographic mobility of industry. Moreover, they emphasize that abatement costs are just too small in most industries in order to affect the industry appreciably (Ederington et al.,2005).

Those findings are confirmed by another study conducted by Naegele and Zaklan (2019). They examined if the EU ETS stringency has a potentially greater impact on footloose industry and they test for nonlinearity of the effect of EU ETS stringency. Their analysis has shown that the impact of emissions costs on manufacturing sectors is statistically alike zero. Therefore, they could not find any evidence that supports the assumption that the EU ETS leads to carbon leakage in European manufacturing sectors. Instead, they suspect that the absence of trade effects displays that the barriers that prevent carbon leakage are higher than the emission cost encouraging leakage. Furthermore, they emphasize that current allowance prices in the EU ETS might be too low, and tariffs and transportation costs are usually higher than costs associated with CO_2. They assume that firms are able to pass thorough at least some of their emissions cost to the end consumer and due their market power they do not loose significant market share. Even though Ederington et al. (2005) and Naegele and Zaklan (2019) could not find direct evidence, the outcome of their analysis is coherent with a negative correlation between footloose industries and abatement costs. This contradicts the findings provided by

Martin, et al. (2014b). They found evidence for a negative correlation between trade intensity and relocation risk.

Nevertheless, it can be seen from the literature review that there is little to almost no research on the correlation between abatement costs and the risk of relocation. The implications for this study and the contributions that this thesis has to the existing literature are described in the following chapter.

3.5 Implication for the study

The previous literature mainly focuses on the classification of sectors in carbon intensive and trade intensive sectors in order to assess if they are at risk of carbon leakage. However, it is still unclear whether this classification is sufficient or whether other factors play an important role in the risk assessment of carbon leakage. Naegele and Zaklan (2019) and Ederington et. al. (2005) find no evidence for carbon leakage, based on the assessment of relocation costs on transportation costs in order to examine the effect of policy stringency on bilateral trade flows. Both studies focus on the proxy relocation costs by assessing transportation costs, instead of examining other relocation costs of firms that may be vary among many factors such as unobservable business opportunities, political risks, exchange rate concerns and the availability of labor in the alternative locations that might limit leakage (Naegele and Zaklan, 2019). The study conducted by Martin et al. (2014b) focuses more on the number of firms moving rather than finding out which companies are moving, as they examine the carbon leakage criteria set by the EC and therefore the sector that fall under these criteria. Ahlvik and Liski (2019) analyse this theoretically and show that if costs and external options are the private information of companies, the risk of relocation of companies leads to more stringent, not too loose local regulations. In the course of this they highlight the importance of this correlation, as they find out that both the strength and the sign of correlation are important for the design of the optimal policy, but they don’t provide evidence for a positive or negative correlation.

This is the point at which this thesis fills the research gap. Although Ahlvik and Liski (2019) suggest that a negative correlation postulates that firms with low abatement costs are the least mobile and a positive correlation leads to the assumption that low-cost firms are the first to leave the EU ETS, they don’t analyse data that confirms these assumptions. This thesis contributes to the existing since it is one of the first study of its sort using data that combines relocation risks with abatement costs. The investigation of differences in the characteristics of treated companies will improve the understanding of the impact of the EU ETS on prevention of emission. Since some researches are assuming that there are too many sectors on the list of sectors affected by CO_2 leakage for example due insufficient choices or indicators, this thesis is intended to enhance the classification of companies actually exposed to carbon leakage by using more accurate criteria (Dröge, 2009).

This work pursues to fill research gaps on two sides. Firstly, it´s being attempted to find an answer to the question of *who is leaving the EU ETS Scheme first?* in order to expand the results of Martin et al. (2014b). Secondly, relocation risk is not determined on the basis of transportation costs but on the basis of "real data", namely, the assessment of the relocation risks by managers of the respective industries that includes firms' private information about costs and outside options. Therefore, this approach leads to more precise results than the assessment of relocation risks based on transportation costs.

Hence this thesis analyzed the correlation between abatement costs and relocation risk of companies that are considered to be at risk of carbon leakage using real data for the first time, and not transportation costs as a proxy for relocation costs. The results might give an indication of the expected impact of abatement costs on relocation risks, considering the pollution intensity of a firm. In the course of this first statements can be made as whether relocation prevents the achievement of climate goals.

In the following chapter the guiding hypotheses to be investigated are formulated. The results attempt to give an indication of such a correlation exists, if so which sign the correlation coefficient reveals (negative/ positive/ zero). Thus, either Ahlvik and Liski (2019) assumptions regarding the coefficient sign can be confirmed or refuted.

3.6 Expected Effects of Abatement Costs on Relocation Risk

The research question of this thesis is as follows:

Is there a correlation between abatement costs and relocation risk across different industries (“footloose” vs.” non -footloose”) under the EU ETS Scheme?

Ahlvik and Liski (2017) assume that in case the correlation is positive low abatement costs are associated with a high relocation risk and therefore only low-cost firms are exposed to carbon leakage and therefore leave the EU ETS Scheme first. Logically, for the opposite case, it is assumed that if the correlation coefficient between relocation risks and abatement costs is negative, the high-cost firms that don’t reduce emissions are the first to move, whereas those firms that cut emissions will stay. It can be deducted that a weak positive correlation would imply that the medium-cost firms leave the EU ETS first. Moreover, no correlation reveals that it can be ruled out that the level of abatement costs has an effect on the risk of carbon leakage.

Based on their research, the following two hypotheses will be probed in order to give an answer to the research question:

1. A positive correlation implies that low abatement costs are associated with low relocations cost.
2. A negative correlation implies that low abatement costs are associated with low relocation cost.

As already mentioned earlier, Ahlvik and Liski (2017) have formulated presumptions about the sign of the coefficients between relocation risk and abatement cost, but they lacked the analyzed data that could confirm their assumptions. This work intends to fill the gap, since interview-based data associated with relocation risk is being used and combined with avoidance costs of the respective industries.

The last hypothesis is based on the exit probability function used by Martin et al. (2014a). The exit probability function shows that the more allowance certificates a company has, the lower its risk should be to leave the regime. The exit probability declines by the amount of free permit qi. Therefore, as a result of the third hypothesis, the relocation risk at 80% free issued certificates should be lower than at 0 % at the same level of abatement costs.

3. According to the exist probability function (please refer to Martin et al, 2014a), a higher number of free allowances (0% vs. 80 %) should lower the Vulnerability Score and therefore the relocation risk.

4. Data

In order to investigate the impact of abatement cost on relocations risk, this work combines two data sets. The starting point of the analysis is the dataset provided by Martin et. al. (2014b). This data is an interview-based measure of vulnerability to carbon leakage. It collects data from management practices relating to climate policy by interviewing managers of manufacturing firms in six European countries about the expected impact of future climate policy on outsourcing and relocation risk.

This dataset is combined with the emission trading data from the EU ETS data viewer. As the literature research already showed, it is pretty complex to determine avoidance costs of CO_2 emissions due information asymmetries. Therefore, a strategy is developed in the following in order to distinguish those sectors that are polluting from those that are cutting CO_2 emissions. In doing so, an impression of which sectors face high abatement costs, and which don't is provided. First, both data records are described including the data collection process of the emission data from the EU ETS data viewer will be highlighted. Second, the median assessment as the strategy to determine avoidance cost is explained and the classification of sectors into cutting and polluting sectors is given. The chapter concludes than with an overview about limitations of the both data sets.

4.1 Data Set Collection Process - Relocation Risk

Due to the problem of asymmetric information on compliance costs between regulator and the regulated, it is difficult to determine which businesses are at risks to relocate (Sato et al., 2015). The data set of Martin et al. (2014b) gives first indications on relocations risk. They conducted interviews with managers from 761 manufacturer companies in order to assess how likely specific sectors in specific countries are to shut down their production sites and relocate them abroad. The sample used by Martin et al. (2014a) consists of manufacturing companies with more than 50 but fewer than 5000 employees for the countries Belgium, France, Germany, Hungary, Poland and UK. Companies under the EU ETS were over-represented with 429 (57%) out of a total of 761 companies interviewed. Managers of companies from the following sectors were interviewed: Cement, Iron & Steel, Textile/Leather, Chemical & Plastic, Wood & Paper, Machinery & Optics, Food/Tobacco, Glass, Other Basic Metals, Vehicles, Fuels, TV/Communication, Ceramic, Fabricated/Metals, Wholesale, Other Business Services, Other Minerals, Furniture/NEC, Publishing. Detailed information on the sample representatives, interview response rates by country as well as on the firm characteristics by ETS participation status can be found in the Appendix displayed in Table A1; Table A2 and Table A3.

The interview format was modeled on the design by Bloom and van Rene (2007). This approach was used to minimize cognitive bias due asking open ended questions and scoring of the answers by the interviewer. In addition, interviewers are rotated to control possible interviewer bias by including interviewer fixed effects in regression analysis (Martin et al., 2014a). The key question of the interview, which is of importance in this analysis, is:

"Do you expect that government efforts to put a price on carbon emissions will force you to outsource part of the production of this business site in the foreseeable future, or to close down completely?"

An ordinal Vulnerability Score (VS) on a scale of 1 to 5 has been used to translate the answers to this question. The analysts were told to give a rating of 5 if the manager anticipates the investment to close completely and a rating of 1 if the manager did not expect any adverse effects at all. A rating of 3 was awarded if the manager expected at least 10% of production and/or employment to be outsourced in response to future policies. Intermediate responses were scored by 2 or 4. A summary of the results from Martin et al. (2014a) on the distribution of VS by country and industry sector (Figure A2) and descriptive statistics of the VS (Table A4) can be found in the Appendix.

It turned out that VS has a mean of 1.87 and a standard deviation of 1.29 across all investigated companies. Managers of ETS companies expect a significantly higher impact (2.14) on relocation decision than non-ETS firms (1.49) in terms of future climate polices. The review of unprocessed data suggests that carbon pricing has a greater impact on relocations decisions in German, French and Polish companies than on UK, Belgian and Hungarian companies. When looking at different industries, Fuels and Other Minerals are the most vulnerable. In all other sectors, the average VS value is rather low (see Appendix Table A4). However, in no industry did the authors find that the complete relocation and closure of plants are in the 95 % confidence interval (Martin et al., 2014a).

Sampling adjustments for this analysis

A limitation for the analysis in this thesis is needed, since the guiding question has been formulated under the EU ETS Scheme. Consequently, the following analysis only covers companies that are included under the EU ETS Scheme. This constraint decreases the total number of companies for the analysis and leaves 429 companies instead of the initially 761. Furthermore, not all sectors that Martin et al. (2014a) have been defined can be taken into consideration, since some sectors couldn't be explicitly identified in the dataset of the EU ETS data viewer and therefore no estimation of the amount of the avoidance costs could be done.

Table 2: Manufacturing sectors covered in the following analysis

Included	Excluded	# of firms interviewed
Cement		46
Ceramics		3
Chemical & Plastic		64
Fuels		12
Glass		24
Iron & Steel		25
Other Basic Metals		4
Other Minerals		5
Wood & Paper		61
	Textile/Leather	10
	Vehicles	23
	TV/Communication	4
	Fabricates Metals	6
	Wholesale	4
	Other Business Services	3
	Furniture/NEC	1
	Publishing	2

Note: Sectors that has been excluded from the analysis due to the lack of availability of data are displayed in the Table 2.

4.2 Data Set Collection Process - Abatement Costs

The literature research has already shown that there is little to no information about the avoidance costs that sectors are facing, especially due to the prevalent information asymmetry between the regulator and the companies to be regulated. To find out which sectors have the highest abatement costs, it is necessary to identify which sectors are reducing emissions and thus sell certificates and which companies continue to emit due high avoidance costs. To identify the sectors that actually cut emissions the data set of the EU Transaction Log (EUTL) were analyzed (European Environmental Agency , 2019b).

The EUTL is also used by Martin et al. (2014a) to assess sectoral trade and carbon intensity data. It covers data on emissions and allocations for Phases I, II & III and represents a central transaction protocol of the European Commission, since it checks and monitored all transactions that take place within the trading system. The EU ETS Data Viewer provides aggregated data by country, by activity type and by year of verified emissions, allowances and transferred units of the more than 12,000 stationary installations reported in the EU ETS and 1400 aircraft operators (European Environment Agency (EEA), 2019a). To ensure data comparability, those sectors and countries were selected which have also been analyzed by Martin et al. (2014a).

As already mentioned, since not all sectors that have been analyzed by Martin et al. (2014a) can also be found in the EU ETS data viewer, the data to be analyzed must be restricted in order to ensure a comparability of Martin's data and those of EU ETS data viewer. The following section describes how the data set of EU ETS data viewer was accessed and subsequently restricted.

Data Collection Process

In a first step, both data sets were compared with each other and the “activities” of the EU ETS Data Viewer were assigned to the sector which can also be found in the data set of Martin et al. (2014a). A complete list of all the activities listed in the data viewer can be found in the Appendix displayed by Table A5. In order to decide which “activity” belongs to which sector, the statistical classification of economic activities of the EC was used (European Commission, 2005). In order to be sure an appropriate allocation was done, it was compared with the one that is provided by the EEA. With an exception of refining of mineral oil, the EEA has made the same sectors classification of activities (see. Appendix Table A6) and therefore supports the allocation that is used in this study. The resulting allocation of activities are listed in the following table:

Table 3: Allocation of the activities to the respective sectors

Activity	Sector	NACE Code
20 Combustion of fuels 21 Refining of mineral oil 22 Production of coke	Fuels	23
23 Metal ore roasting or sintering 24 Production of pig iron or steel	Iron & Steel	271,272,273,275
25 Production or processing of ferrous metals 26 Production of primary aluminum 27 Production of secondary aluminum 28 Production or processing of non-ferrous metals	Other Basic Metals	274
29 Production of cement clinker 30 Production of lime, or calcination of dolomite/magnesite	Cement	264, 265,266
31 Manufacture of glass	Glass	261
32 Manufacture of ceramics	Ceramics	262
33 Manufacture of mineral wool 34 Production or processing of gypsum or plasterboard	Other Minerals	267,268, 265
35 Production of pulp 36 Production of paper or cardboard	Wood & Paper	20,21
37 Production of carbon black 38 Production of nitric acid 39 Production of adipic acid 40 Production of glyoxal and glyoxylic acid 41 Production of ammonia 42 Production of bulk chemicals 43 Production of hydrogen and synthesis gas 44 Production of soda ash and sodium bicarbonate	Chemical & Plastic	24,25

Note: The table was created by the author herself. It matches the data from EU ETS Data viewer (European Environment Agency, 2019b) to the sectors used by Martin et al. (2014b). The NACE Codes display the statistical classification of economic activities in the European community. NACE is a four-figure system and provides the framework for the collection and presentation of a wide range of statistical sector-by-sector economic data. (European Commission, 2016)

In a next step, the respective data for the emissions was extracted from the EU ETL data set in order to compare emissions from the years 2005-2017 (European Environmental Agency , 2019b). The presets “Emissions by sector”, the years “2005-2017”, the "verified emissions", the above-mentioned countries (Belgium, France, Germany, Hungary, Poland, UK) and the activities listed in Table 3 were selected. Afterwards sectors were classified into polluting and cutting sectors with the help of the median assessment, that is described below.

Polluting and Cutting CO_2 sectors

To divide sectors into CO_2 issuers and sectors that actually reduce emissions, the method of median calculation was chosen. First of all, the average of emissions for each sector for the years 2005-2011 and for the years 2012-2017 was calculated. Afterwards the average change (average emissions 2012-2017/average emissions 2005-2011) was determined for each sector and based on this an overall median was defined (0.9981). Thereafter, the main independent variable in form of a dummy variables was generated by assigning a zero to each average change value above the median and a 1 to those emission values that were below the median. In other words, a 0 is assigned to those sectors that are considered as CO_2 issuers and a 1 to those that reduce emissions. The median method also ensures that sectors are treated differently in the selected countries. Cement for example were classified in UK as a polluting emissions sector and in all other countries as cutting CO_2 sector. A more detailed overview of the results is provided in the Appendix by Table 8. Afterwards the newly generated dummy variable called *low-cost* is added to the edited data set provided by Martin et al. (2014a).

4.3 Descriptive Statistics

All countries have a VS from 1-5 besides Hungary where no company records a VS of 4 and 5 and UK where no VS of 5 is listed. Most of the companies considered in the analysis are located in France (53), the least in Hungary (25). The mean of the VS for most countries is between 1 and 2, whereas Hungary has the lowest value compared to all other countries with 1.12. This indicates a pretty low risk of relocation for the majority of companies located in Hungary. The highest relocation risk exists for companies located in Germany with a mean of 2.045. This is supported by the results of the mean of the low-cost variable, which is for Germany below 0.27. In other words, most of the sectors in Germany were assigned with a 0 for non-cutting emissions.

Additionally, even though Germany and Hungary have the same amount of cutting and polluting sectors, overall Hungary is considered as emission reducing (low-cost variable = 1), whereas Germany as emission polluting (low-cost variable = 0). Being more specific, in Germany the average change in sectors that are polluting is bigger than those which are reducing emissions, while it’s the other way around in Hungary. Sectors such as Chemical & Plastic (+30%), Other Basic Metals (+2392%) as well as Iron & Steel (+ 69%) are responsible for the fact that Germany is overall speaking considered as a polluting country, since they record the highest increase in the average change in emissions issuing in the respective time (see Appendix Table 8). However, it must be added that even though the sector Other Basic Metals records by far the highest percentage change, this needs to be put in perspective, since in total numbers it has the third lowest emission amount in tones (after the sectors Other Minerals and Ceramics). Between 2005-2017 companies of the sector Other Basic Metals polluted a total of 34,608 tones CO_2 whereas the sector Fuels for example records a total of 4915,233 emitted tones of CO_2 in Germany (Appendix Table 8). Consequently, the total number of emissions needs to be taken into consideration if the average change is assessed. Especially when conclusions are generally drawn about the harmfulness of different sectors.

In contrast the sectors Ceramics (-61%), Fuels (-26%) and Iron & Steel (-28%) are responsible that Hungary is acknowledged as a cutting emissions country. Furthermore, Germany and Poland are the only countries that are considered as polluting countries (low-cost variable = 0). All other countries are acknowledged as overall cutting emissions (low-cost variable = 1).

Table 4: Descriptive statistics of the Vulnerability Score (80%)

Country	Mean	SD	P25	P50	P75	Min	Max	N
Belgium	1.34	.788	1	1	1	1	5	47
France	1.736	1.095	1	1	2	1	5	53
Germany	2.045	1.478	1	1	3	1	5	44
Hungary	1.12	.44	1	1	1	1	3	25
Poland	1.811	1.126	1	1	3	1	5	37
UK	1.703	.968	1	1	2	1	4	37

Sector	Mean	SD	P25	P50	P75	Min	Max	N
Cement	1.578	1.076	1	1	2	1	5	45
Ceramics	1.333	.577	1	1	2	1	2	3
Chemical & Plastic	1.469	.908	1	1	1.5	1	5	64
Fuels	2.167	1.337	1	2	3	1	5	12
Glass	1.958	1.367	1	1	3	1	5	24
Iron & Steel	2	1.291	1	1	3	1	5	25
Other Basic Metals	1.25	.5	1	1	1.5	1	2	4
Other Minerals	2	1.732	1	1	2	1	5	5
Wood & Paper	1.574	.974	1	1	2	1	5	61

Note: The table 4 shows the mean value, the standard deviation (SD) from the mean, value the number of observations, percentiles (p25, p50, p75), the minimum value/ the maximum value for VS and the number of observations.

If a closer look is taken on the VS by sector, it is noticeable that for most of the sectors the mean of the VS is between 1 and 2, which indicates that on average the relocation risk is pretty low. The highest VS and therefore the highest relocation risk on average are associated with companies of Fuels (2.167). In respect to the low-cost variable it is observable that for Other Basic Metals, Chemical & Plastic and Other Minerals no mean and therefore no standard deviation is available. This can be explained by the fact that for Chemical & Plastic is in none of the countries classified as a “cutting emissions” sector. Therefore, this sector was not treated at all. The sectors Other Basic Metals and Other Minerals were declared as reducing sectors in the UK, but since no data on these sectors in the UK were available, no mean was recorded.

In respect to the other sectors, the mean of Cement, Fuels and Iron & Steel is around 0.7, which means in most of the countries those sectors rather cutting than polluting emissions, since their mean of low cost- variable is closer to 1 (= cutting emissions) than to 0 (= polluting emissions).

The mean for the low- cost variable of the sectors Glass and Wood & Paper is around 0.5 that shows that these sectors cut and pollute emissions equally among the surveyed countries. Ceramics recorded a mean of 0.33, consequently this sector is in most of the countries rather considered as polluting than cutting emissions (see Figure 9).

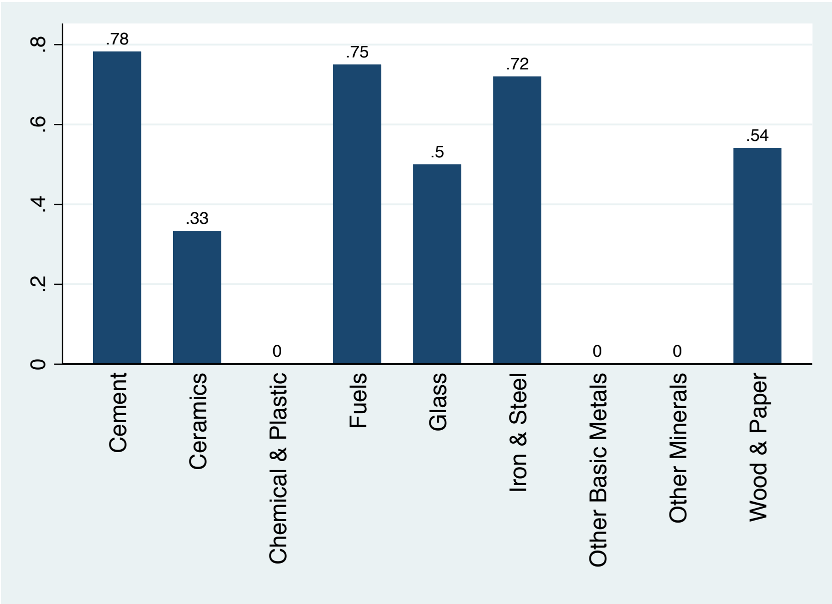

Figure 9: Mean of the low-cost variable by sector

In terms of the low-cost variable by country, UK (35/38) and Germany (32/44) record the highest share of polluting companies (low-cost variable =0), whereas France (13/53) and Hungary (8/25) are documented as having the lowest share of companies that don’t cut their emissions (see Figure 10). Possible explanations are given in the course of the discussion.

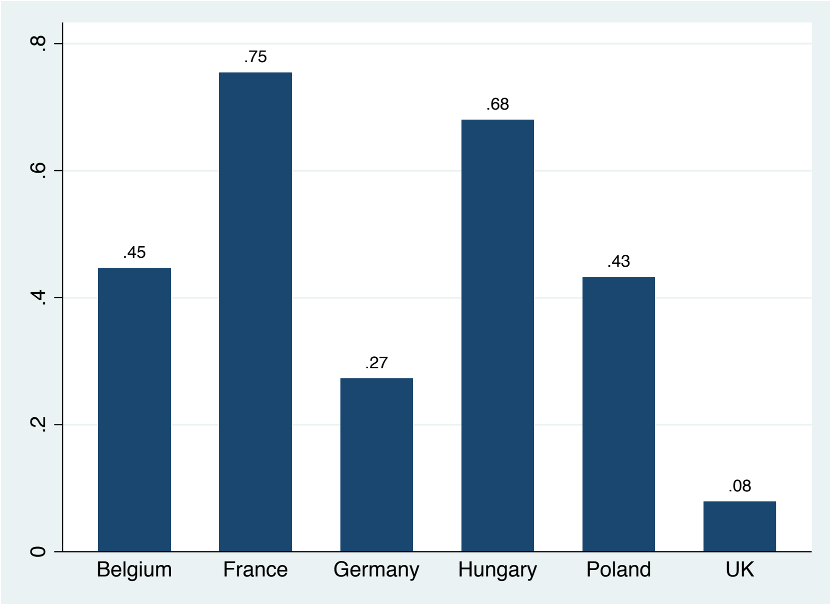

Figure 10: Mean of low-cost variable by country

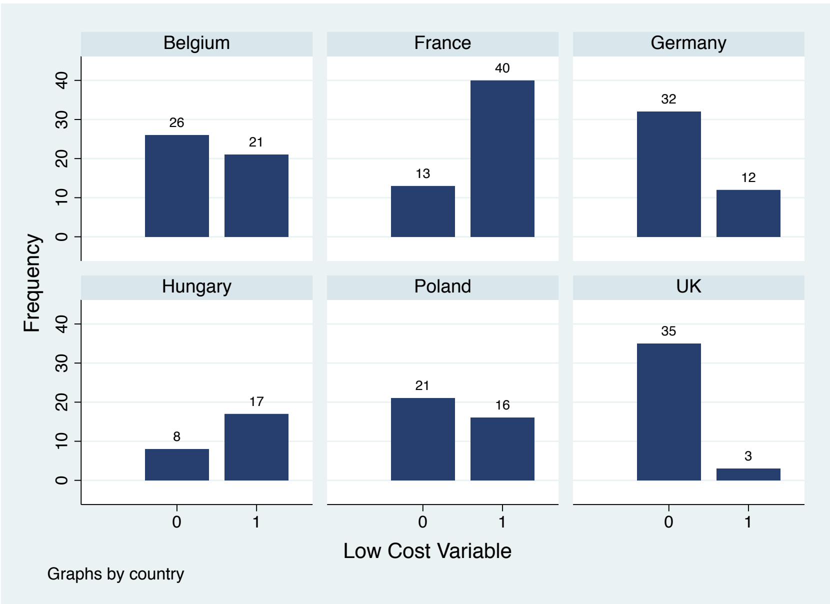

Figure 11: Distribution of companies that pollute/cut emissions on country level

Note: The low-cost variable represents a dummy variable, that distinguish between cutting (=1) and polluting companies (=0). Those companies that are associated with emissions pollution are assigned with a 0, those that are considered with the reduction of emissions get a 1.

Since already mentioned above, the data sets suffer from limitation such as the comparability of the results of the median calculation. In the following section, limitations of the two datasets are examined in more detail and their conditional comparability discussed.

5. Empirical Strategy

The following analyses aim at identifying the impact of abatement costs on relocation risk. It follows empirical strategies that take in consideration VS differences in sectors and countries. Sectors which were identified as comprising polluting industries tend to have a higher VS and therefore a positive correlation between abatement costs and relocation risk. Consequently, it is expected that those sectors that were identified as cutting pollution sectors have a lower Vulnerability Score, and thus tend to have a negative correlation between abatement costs and relocation risk. However, as discussed in in the literature review, correlations and their respective signs are difficult to predict a priori.

In order to analyze the effect of abatement costs on relocation risk, a “fixed effects” analysis is conducted. The sample examined consists of 244 observed data. It includes information at country levels as well as at sector levels. The “fixed effects” method is introduced in section 5.1 as a regression model, followed by the proper “Regression Model” applied in this thesis.

5.1 The Fixed Effects Method

In general, the “fixed effects” regression model is used to minimize bias effects on observed data by eliminating parts of the variation that are believed to contain confounding factors (Mummolo & Peterson, 2018). Those are dimensions of individual-specific (here sectors or countries) effects that are somehow correlated to explanatory variables. Consequently, the parameter selection and its valuation may be biased due to these omitted effects. One reason for such an omission may lie in the misspecifications used for construing an appropriate linear regression. Another reason could be the unknown effect of the omitted variable on the dependent variable. Or the data for these variables is simply not available. If researchers decide to use the “fixed effects” method as their methodology, they narrow the analysis to a specific dimension of the data, e.g. a within-country variation. If on the other hand within-unit variation is prioritized, researchers put aside the consideration of between-unit variations since it is barely the case that between-unit variation provide reasonable estimates of an influential effect (Mummolo & Peterson, 2018).

Fixed effects regressions are highly important since data often fall into categories like industries, states, families, etc. By including fixed effects, also called “group dummies”, average differences across individualities are controlled within any observable or unobservable predictors (Blumenstock, 2013). The fixed effect coefficients absorb all the across-group action and therefore reduces the threat of omitted variable bias. In this thesis the fixed effects model is used to control sector and country specific effects. Those are represented by dummy variables in the regression, one for each sector and one for each country in the sample. Both variables show cross sectional heterogeneity that is absorbed by fixed effects models (Dewan & Kraemer, 2000).

While the combination of data from different countries and sectors expands the variation in the variables, which, of course, in a statistical perspective seems to be very attractive, it is indispensable to take country effects and sector effects respectively and independently into account. Countries for example are likely to systematically differ in terms of weather, infrastructure, productive efficiencies etc. The same applies to sectors: they could differ in production processes, technologies they use, process emissions and product mix differences (Sato et al., 2015)

The Basic Fixed Effects model is given by

$$(1) \quad Y_{\mathrm{it}} = \alpha_{\mathrm{i}} + \beta X_{\mathrm{it}} + \epsilon_{\mathrm{it}}$$

(Mummolo & Peterson, 2018)

Y represents the outcome; the independent variable X is defined for each unit *i* for exemplified countries over various time periods *t*. The intercept α is estimated for each unit *i* in order to include distinct and time invariant features of each unit. As a result, the value of ß does not depend on between-unit and time invariant cofounders.

Since fixed effects models are normally used to analyze panel data, two basic data requirements for using fixed effects exist: first, the independent variable must be captured for each unit on at least occasions, and second, those measurements must be comparable, so they need to have the same meaning and the same metric (Allison , 2009).

Typically, *t* is indexing over time, but in a mathematically way, there is no reason why it can't be anything else. In this case the standard fixed effects model is modified: *i* is replaced by c and *t* is replaced by s. Therefore, c is indexing over countries and s over sectors:

$$(2) \quad Y_{\mathrm{cs}} = \alpha_{\mathrm{i}} + \beta X_{\mathrm{cs}} + \epsilon_{\mathrm{cs}}$$

Since the data used in this work represents a combination from individual level (VS) and contextual level (country level/sector level-based emissions data), several problems could arise in connection with country comparative studies. For instance, some data sets that are used for multilevel models only consists of a small number (N<25) of macro level units. This results in a small number of degrees of freedom on a country level and only a few macro level indicators can be accounted for. As a result, country estimators in those models are likely to encounter omitted variable bias. The fixed effects method serves as an alternative to the utilization of conventional multilevel methods in country comparative analysis. One of the benefits of the fixed effects approach is the application to a small number of countries. In addition, it avoids the omitted variable bias by keeping country level heterogeneity under control (Möhring, 2012).

Nevertheless, even the fixed effects method would not completely eliminate potential omitted variable bias, since it is not possible to assess the effect of variables that have small within-group variations (Blumenstock, 2013). Another disadvantage of using fixed effects would be that constant or "fixed" variables as explanatory variables in the model would no longer directly be included. Although the fixed effects method is almost exclusively used in conjunction with panel data, it will be applied for the abovementioned reasons on cross-sectional data in this work.

5.2 The Regression Model

In order to determine any correlation, the data set provided by Martin et al. is linked to a dataset from the data viewer of the EU ETS. In more detail, relocation risk is represented by the VS obtained by Martin et al. (2014b) and the abatement costs are displayed by the emissions data extracted from the data reviewer of the EU ETS. As outlined in section 4.2, sectors and countries have been divided into polluting and cutting categories using the median method. From this division, a new dummy variable (the low-cost variable) was generated. Thus, the equation formulated by Martin et al. (2014b) is modified to include the low-cost variable and a set of control variables that were perceived as relevant. If control variables are not included, some of the variation will be inappropriately attributed to the treatment or the dummy variables. Consequently, the value of the independent variable would be biased, which would then be accounted to an omitted variable bias (Mummolo & Peterson, 2018).

Modified equation:

$$(3)\quad Y_{i,s,c} = \alpha_0 + \beta_T LowCost + \beta_x x'_{i,s,c} + \delta_c + \delta_s + \varepsilon_{i,s,c}$$

Y represents the VS of a firm i in sector s and country c if firms don't get permits allocated for free (0%). The variable "LowCost" represents whether a firm is identified as polluting emissions (treatment = 0) or cutting emissions (treatment =1). In addition, $x'_{i,s,c}$ display control variables such as firm level employment, that is averaged over the years from 2005-2008 and quadratic forms of the TI and CI variables, which are supposed to capture possible effects of interactions and non-linearities (Martin et al., 2014b).

The fixed effects method is represented by country dummies δ_c and sector dummies δ_s. If sector/countries invariant characteristics are not under control, the regression could be biased. Thus, unexpected variation or special events that might affect *Y (VS)* are controlled. Examples of such events that are common for all sectors could be differences in product mixes, implemented technologies or recycling rate differences. On a country level, differences in politics or product could be considered in respect to invariant characteristics (Sato et al., 2015).

The Vulnerability Score for 80% free allocation of permits as the dependent variable is chosen for this model, because it represents the policy context that firms receive all permits for free, which is going to be the case in the future. It must also be mentioned that the log version of the VS was taken, since this model gave the most significant results.

6. Empirical Analysis

In the following section, the effect of abatement costs on relocation risk is estimated. Based on the relocation risk sourced from individual data and emission data from 9 sectors within 6 countries, a "fixed effect" analysis is conducted to assess a possible correlation between abatement cost and relocation risk. The analysis consists of two parts. The results of the main regression are first presented. Robustness tests are then conducted to check the sensitivity of the outcome. The section concludes by summarizing the results.

6.1 Main Results

Table 5 reflects the main results from the regression model described in the previous section.

Table 5: Estimates for the Vulnerability Score for 80% of free permits

	(1) NoFE	(2) SectorFE	(3) CountryFE	(4) BothFE	(5) NoFE	(6) SectorFE	(7) CountryFE	(8) BothFE
Low- cost	-0.060	-0.208**	-0.019	-0.227**	-0.094	-0.201**	-0.072	-0.210**
	(0.067)	(0.092)	(0.074)	(0.108)	(0.079)	(0.091)	(0.088)	(0.106)
TI					-0.002	-0.002	-0.003	-0.002
					(0.002)	(0.002)	(0.002)	(0.002)
CI					-0.004	-0.015	-0.008	-0.021
					(0.013)	(0.013)	(0.012)	(0.013)
TI x TI					0.000	0.000	0.000	0.000
					(0.000)	(0.000)	(0.000)	(0.000)
CI x CI					0.000	0.000*	0.000	0.000**
					(0.000)	(0.000)	(0.000)	(0.000)
CI x TI					0.000	0.000	0.000	0.000*
					(0.000)	(0.000)	(0.000)	(0.000)
Employment (ln)					0.024	-0.003	-0.001	-0.026
					(0.027)	(0.029)	(0.029)	(0.030)
Obs.	243	243	243	243	243	243	243	243
Sector Dummy	No	Yes	No	Yes	No	Yes	No	Yes
Country Dummy	No	No	Yes	Yes	No	No	Yes	Yes

Standard errors are in parenthesis

*** p<0.01, ** p<0.05, * p<0.1

Notes: Logit-level model in all columns. The dependent variable is the Vulnerability Score of the firms in case 80 % of the permits are given out for free. Column (1) to (4) don´t include control variables, whereas column (5) to (8) do. As explanatory variables, CI indicates carbon intensity and TI indicates trade intensity. TI x TI, CI x CI and CI x TI display the interaction of those two variables. Employment are averaged over the years from 2005 to 2008. The data excerpt for the low-cost variable (self-generated) is taken from Martin et al (2014b).

In a first step, the regression is carried out without using control variables (column 1-4). The VS is regressed on the low-cost variable, first without fixed effects. Sector fixed effects are then introduced, followed by country fixed effects. The last regression includes sector and country fixed effects.

The same procedure was accomplished with control variables such as trade intensity, carbon intensity, employment (ln) as well as with quadratic forms of the TI and CI variables. The results are displayed in column (5)-(8). As a base case/reference category for the sector fixed effects model, the dummy variable "Iron & Steel" is used, as is the dummy variable "Belgium" for the country fixed effects model.

In order to interpret the results, it must be mentioned that percentage specifications of the VS have already been fixed by Martin et al. (2014a). They have classified the VS as follows: a score of 1 was assigned if the managers were assuming that 1% of the production and /or the employment would be relocated as a consideration for future policies, a score of 2 if they expected a relocation of 5%, a 3 for a 10% relocation, a 4 was assigned for 50% of relocation and a 5 for 90% of relocation. Consequently, smaller effects can be expected from going from a VS of 3 to a VS of 4 for example than from a VS of 1 to a VS of 2.

The respective coefficient of low-cost variable for all above specifications is negative. It is furthermore significant at a 5% level in the case of sector fixed effects and both fixed effects. The introduction of sector fixed effects leads to a decrease of 20.8% of the VS for treated sectors (having low abatement costs) without control variables and to a decrease of 20.1% with control variables.

If both fixed effects are introduced, the VS of cutting sectors decreases by 22.7% without control variables and 21.0% with control variables, significant at a 5 % level. In respect to the abovementioned percentage specification, if a manager of company in a treated sector is assigned a VS of 3, the introduction of sector fixed effects lowers the VS to 1. In case of assigned VS of 4 or 5, VS would decrease relatively, but won't change the category of the assigned VS, since the percentage change in itself is relatively low. In addition, it can be seen that including control variables lowers the value of each coefficient, even though they have a very low impact on the independent variable. This phenomenon should be expected, as already mentioned above, adding more independent variables to the regression lowers the probability of omitted variables bias and therefore influences the value of the coefficient.

The introduction of "sector fixed effects", hence comparing the same sectors across different countries, increases the negative impact of the low-cost variable on the VS, whereas the coefficient of the model that includes both fixed effects (country and sector) has the highest negative impact.

In order to describe the implications of "fixed effects" on the coefficient, it can be said that the fixed effects model in all regressions eliminates sector/country invariant confounding factors, estimating an independent variable effect by using only within-unit variation in order to reduce omitted variables bias. The fact that the coefficients of the remaining fixed effects model are negative signifies that sectors that are cutting pollution (low-cost variable=1) have a lower VS and therefore have a lower relocation risk than sectors that are identified as polluting industries (low-cost variable=0). If it is not controlled for sector fixed effects, the results still hold.

In terms of the control variables, no control variable is significant and therefore no impact on the VS that could be generalized can be noted. But the coefficients of the variables for TI and CI are having both a negative sign. This could indicate that trade intensity and carbon intensity tend to reduce the relocation risk of cutting companies. This stands in contrast with the findings of Martin et al. (2014a), where it is rather assumed that carbon intensity increases the relocation risk. The impact of these two indicators should be further investigated through further research. The coefficient for employment is not significant and has a negative sign if fixed effects are introduced. This is in line with the findings of Martin et al. (2014a). In terms of the quadratic form of the TI and CI variables, all of them have no impact on the independent variable since their coefficient values 0, CICI is significant at a 1 % level if sector fixed effects are introduced and at a 5% level if both fixed effects are introduced. Consequently, no evidence can be found that only TI matters for very high values of TI. This applies as well for high values of CI. Furthermore, the correspondence of CI and TI (CI * TI) doesn't influence the VS. Moreover, removing control variables does not alter the sign of the estimates.

The regression shows that some coefficients of the dummy variables are significant. In respect to the sector dummies, the regression without control variables, that includes sector and both fixed effects, shows that the coefficient of the dummies Chemical& Plastic and Other Basic

Metals are significant at a 5 % level. For instance, if a company is assigned to Chemical & Plastic (or Other Basic Metals) and does cut emissions, the VS decreases by 40% (48.2%) if sector fixed effects are introduced. The effects even get stronger if control variables are included. The coefficient of sector Ceramics is weakly significant at a 10 % level, if sector fixed effects are introduced.

Regarding the country dummies, the coefficients of France and Poland are significant at a 5% level and the one of Germany at a 1% level. If country fixed effects are introduced, the VS of a company located in Germany that is cutting emissions decreases by approx. 30%, by 23.8% for a company located in Poland. The exact distribution of the dummy coefficients and their confidence intervals on a sector as well as on a country level is shown by the following figure.

(a) Sector level (b) Country level

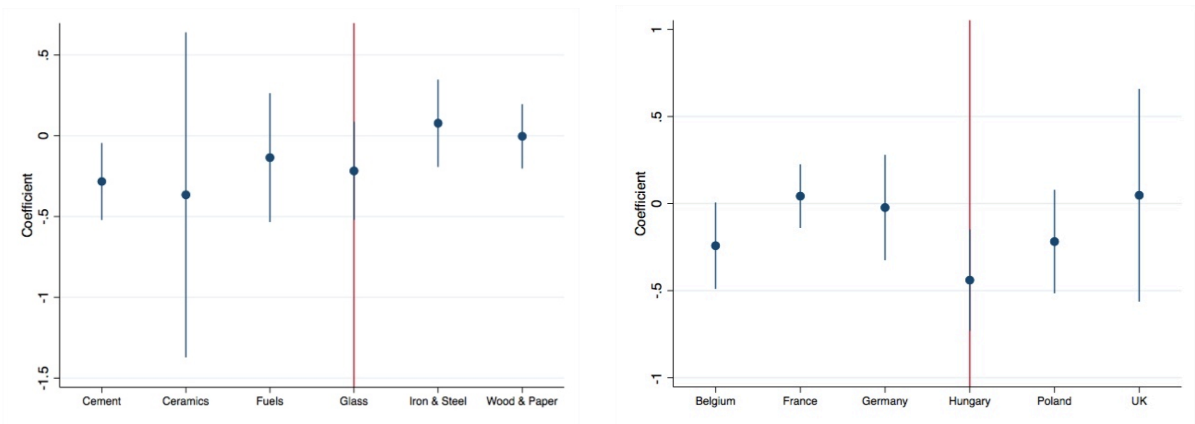

Figure 12: Estimates of the impact of abatement costs on relocation risks

Notes: The figures show the treatment effects from the specification in Equation XX as well as the 90 % and 95 % confidence intervals. Panel (a) shows the effect on sector level, panel (b) shows the effect on country level. The sector Chemical & Plastic is missing in the illustration, since it was in none of the countries classified as a "cutting emissions" sector. Therefore, this sector was not treated. The sectors Other Basic Metals and Other Minerals were declared as reducing sectors in the UK, but since no data on these sectors in the UK was available, they do not appear in the table. A more detailed illustration on which sector was treated and which wasn't can be found in the Appendix Table A9).

Figure 12 plots the coefficient estimates of the treatment variable, on a sector level and county level as well as the 90% and 95% confidence intervals. All control variables and the full sample is included in the estimates. As the results in figure 12 show, the sector Ceramics has the most negative coefficient, followed by Glass and Cement. On other words, companies in these sectors that reduce emissions have comparatively the largest decrease in VS. The sector cement is statistically significant at a 5 % level if sector fixed effects are introduced and control variables included. The sector ceramics turned out to be weakly significant at a 10% level if sector fixed effects are introduced but no control variables are included. On a country level, the coefficient of UK turned out to be weakly significant at a 10% level, the results of Poland and France are both significant at a 5% level and the coefficient of Germany is highly significant at a 1% level.

To sum up, the fact that the coefficients of the low-cost variable are negative in all specifications of the model means that sectors that are cutting pollution (low-cost variable=1) record a lower VS, and therefore, have a lower relocation risk than sectors that are identified as polluting industries. Consequently, no evidence of carbon leakage can be found.

Although the focus of the analysis lies on the case where 80% of certificates are issued free of costs, the case in which no certificate is given out for free will be briefly presented in the following. This is done to determine the influence of policies on the attitude of managers, in relation to the allocated VS.

There are some differences in the comparison of the results. It is noticeable that coefficient of the low-cost variable is not significant at any level. The only variable that turns out to be slightly significant at a 10% level is the trade intensity variable if country fixed effects are introduced and control variables are accounted for. The remaining coefficients are insignificant. They are statistically undistinguishable from 0. Thus, the mean of the Vulnerability Score is not in a statistically significant way dependent on the x´s in this regression.

Table 6: Estimates for the Vulnerability Score for 0% free permits

	(1) NoFE	(2) SectorFE	(3) CountryFE	(4) BothFE	(5) NoFE	(6) SectorFE	(7) CountryFE	(8) BothFE
Low- cost	0.024	-0.128	0.061	-0.168	-0.027	-0.121	-0.021	-0.153
	(0.085)	(0.106)	(0.095)	(0.128)	(0.095)	(0.105)	(0.111)	(0.127)
TI					-0.004	-0.001	-0.005*	-0.002
					(0.002)	(0.003)	(0.002)	(0.003)
CI					0.006	-0.004	0.004	-0.007
					(0.015)	(0.018)	(0.016)	(0.018)
TI x TI					0.000	0.000	0.000	0.000
					(0.000)	(0.000)	(0.000)	(0.000)
CI x CI					-0.000	0.000	0.000	0.000
					(0.000)	(0.000)	(0.000)	(0.000)
CI x TI					0.000	0.000	0.000	0.000
					(0.000)	(0.000)	(0.000)	(0.000)
Employment (ln)					0.053	0.037	0.031	0.016
					(0.036)	(0.040)	(0.037)	(0.041)
Obs.	244	244	244	244	244	244	244	244
Sector Dummy	No	Yes	No	Yes	No	Yes	No	Yes
Country Dummy	No	No	Yes	Yes	No	No	Yes	Yes

Standard errors are in parenthesis

*** p<0.01, ** p<0.05, * p<0.1

Notes: Logit-level model in all columns. The dependent variable is the vulnerability score of the firms in case 0 % of the permits are given out for free. Column (1) to (4) don´t include control variables, whereas column (5) to (8) do. As explanatory variables, CI indicates carbon intensity and TI indicates trade intensity. TI x TI, CI x CI and CI x TI display the interaction of those two variables. Employment are averages over the years from 2005 to 2008. The data except for the low-cost variable (self-generated) is taken from Martin et al (2014b).

Although, all coefficients are insignificant (except for one), the signs of the treatment variable give indications that even if no certificates are issued for free, those sectors that are cutting pollution have a lower VS than those that are polluting, as the sign is negative in most of the model's specifications. It can be concluded that even if companies get 0% of their certificates for free, no evidence for carbon leakage was detected. Furthermore, it can be said that the incident that the coefficient for 0% of free permits is weaker than for 80% confirms the third hypothesis, which says that the more permits will be handed out for free, the less likely it is that companies exit the EU ETS.

6.2 Robustness Checks

The reason for a robustness check is to test how the regression coefficients estimates change, if, and when, the regression specifications are modified. Are the coefficients plausible and robust, this will usually be interpreted as evidence of structural validity (Lu & White, 2014). To test if the regression estimates are robust, two intuitive robustness checks are conducted. First, the heterogeneity of the low-cost variable is evaluated, examining the heterogenous effects by industry and country. A robustness check may also reveal weaknesses in the model as it represents a key indicator for the reliability of the results. One of the concerns might be that the regression results are driven by few sectors, also highly concentrated in few countries.

Heterogeneity attached to the low-cost variable

The method chosen to check the heterogeneity is to reproduce the model with a set of alternative dummy variables. The data from the data reviewer is divided into 10% increments, starting with the highest average change of emissions from 2005-2017. Consequently, the last 10% are assigned to those sectors in countries where average percentage changes in emissions values have been the lowest. The regression is applied on each of the increments to show that the results from the original regression is not driven by specific sectors in specific countries. The results are shown in Figure 13, whereas the original regression is displayed in the top row, followed by the individual increments. Both diagrams give almost the same results, therefore no big difference can be determined in terms of control variables. The results of the test show that the baseline regression is robust and in line with the expectations. None of the test results change the estimates of the baseline results considerably. Even though the increments from the sixth and seventh 10% are having a positive coefficient, the effects are canceled out by the negative coefficient of the remaining increments.

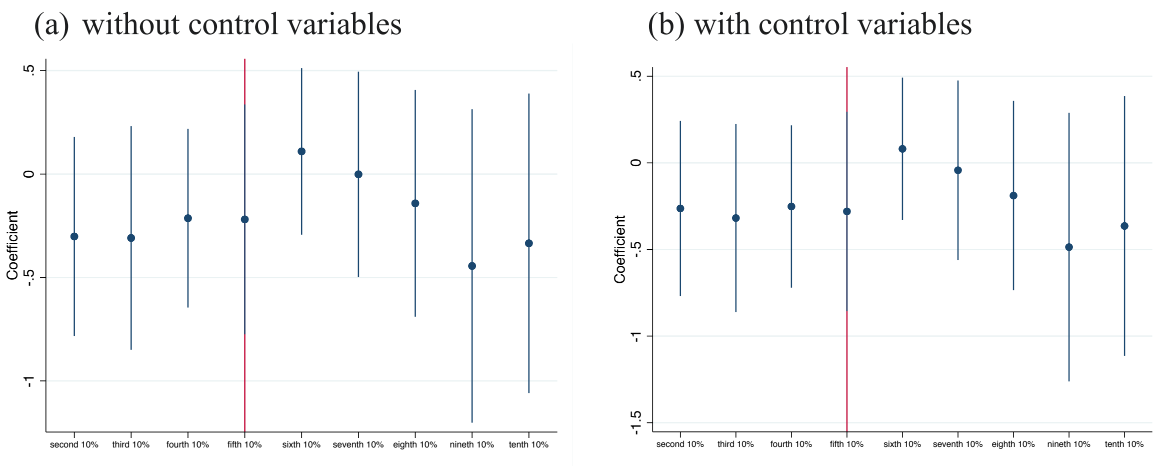

Figure 13: Heterogeneity by the low- cost variable

Note: Diagram (a) represents the respective regression excluding control variables and Diagram (b) includes control variables. Both types of regressions where conducted by introducing country and sector fixed effects. The first 10% increment is omitted.

However, there is a clear shift in the sign of the coefficients, since they change their signs from being negative in the fifth increment to being positive in the sixth increment. This result coincides with those of the median calculation, where the boundary between emission-emitting and emission-reducing sectors was also obvious between the fifth and the sixth increment (see Appendix Table A10).

The coefficient of the ninth increment is the most negative while the only one that is statistically significant is found at a 10% level. These are noticeable results. It was expected that the coefficient of the ninth increment would be in the positive, since they were in the range where the sectors were categorized as polluting entities. This result can mainly be explained by the sector types in this area: four of the five values in this section are assigned to the sector Chemical & Plastic (see Appendix Table A10). The VS of this sector accounts for a score of 1 for more than half the figures. This suggests that a low rate in reduction of emissions cannot be linked to high relocation risk in every sector.

The same applies to the 10^{th} increment that is expected to have a positive coefficient instead of a negative one. In this case, most values can be assigned to “Other Basic Metals”, where the mean of the VS score is around 1. Therefore, it can be concluded that even sectors that are considered as emission-intensive are not at risk of carbon leakage.

Heterogeneity of effects (on industry/country level)

Previously, the variable "low-cost" was tested for heterogeneity in order to examine if the results would be affected by outliers. The same is now done at an industry and country level. This will determine if the effect is driven by a specific industry or by a specific country. The generated low-cost variable might have affected different industries or countries in various ways.

Therefore, the main purpose of this "robustness check" is to estimate the differences of the effect of the low-cost-variable approach across subjects on VS. In order to investigate the differences, dummy variables for each subject, as for each industry and each country were generated. Then a variable which depicts the interaction of the low-cost variable with each subjects' dummies (i.industry*low cost variable/ i.country*low cost variable) were defined. The original regression was then computed with the new generated variables, once with control variables and once without. Using the industry level dummies would leave country effects unvaried. And vice versa. In the following the results of the regression are displayed, starting with the table showing the results on industry level (industry dummies are included).

(a) without control variables (b) with control variables

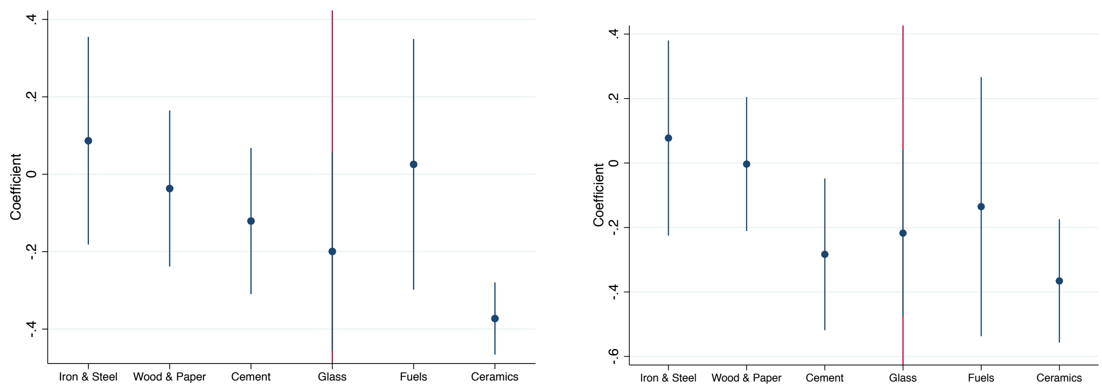

Figure 14: Heterogeneity of effects on industry level

Note: The sector Chemical & Plastic is missing in the illustration, since it was in none of the countries classified as a "cutting emissions" sector and therefore the low-cost variable equals 0. The sectors Other Basic Metals and Other Minerals were declared as reducing sectors in the UK, but since no data on these sectors in the UK is available, they do not appear in the table. For more information on SD, mean and 95% confidence interval refer to Table A11 B&C in the Appendix.

The most negative coefficient can be associated with the sectors Cement, Glass and Ceramics, the only positive values belong to the sectors Fuels and Iron & Steel. The strongest negative effect is associated by far with the sector Ceramics. Therefore, it seems likely that Ceramics has a greater impact on the VS results than other sectors, if country effects are introduced. But it needs to be mentioned that Ceramics just have one value that is recorded to cut emissions. That might also explain the large confidence interval of this sector. The remaining sectors cancel each other out in terms of their effects. If both figures are compared with each other it becomes clear that control variable attenuates the effects of each industries on the VS. But this is an expected effect: the more independent variables are included in the model, the lower is the probability of omitted variables bias. The effects on the dependent variable of each subject coefficient are weakened. Another noticeable feature is that the confidence intervals of the sectors Fuels, Glass and Iron & Steel are relatively large. This can be explained either by a small sample size of values taken that record that these sectors cut emissions (Fuels=9, Glass=12, Iron & Steel=18) or by the dispersion. A high dispersion leads to a less certain conclusion and therefore the confidence intervals becomes wider. The standard deviation of these sectors is very large for the aforementioned sectors (see Appendix Table A11 A & B). That might explain the width of the confidence interval.

The same procedure was done at a country level, the results are displayed by the following figure (only country related dummies are included).

(a) without control variables (b) with control variables

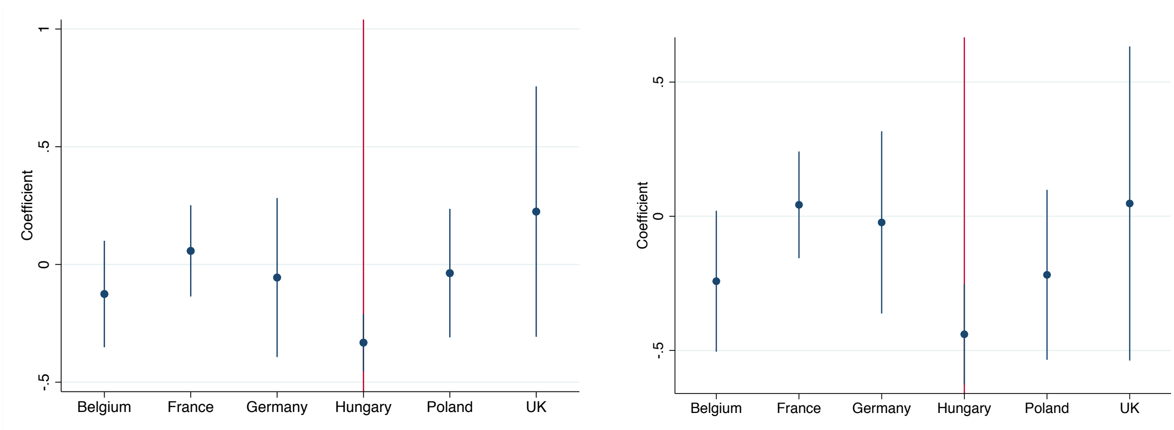

Figure 15: Heterogeneity of effects at country level

Note: On SD, mean and 95% confidence interval please refer to Table A12 B&C in the Appendix.

The values of the coefficients of the countries Belgium, Germany and Poland are about the same, negative but close to zero. Even though the coefficient of France shows a positive value, it is also close to zero. The countries Hungary and UK turn out to be outliers. If control variables are included, the effect of UK is not as strong anymore, but the effect of Hungary keeps unchanged. Consequently, Hungary has a greater negative effect than other countries if sector fixed effects are included. Additionally, Hungary and UK reveal a relatively large confidence interval. This can be explained for Hungary and UK by the combination of a small sample (Hungary=17; UK =3) with a high dispersion (see Appendix Table A12 A&B). Another remarkable point is UK and France having a positive coefficient, which means that the sectors identified as low cost have a higher VS value than those that are not, although no indication of carbon leakage was found in the analysis.

Overall it can be said that the correlation is as well negative as positive for some industries. This applies also for some countries. As a result, the effects do cancel each other out when the "average" effect is estimated. However, it turned out at the industry level that effects are driven by Ceramics and are therefore larger for this industry. At a country level it would be case for Hungary and UK.

6.3 Summary of the Results

The findings explain why evidence for carbon leakage is difficult to find. Companies reducing CO_2 emissions are not at risk of displacing carbon emissions outside of the EU ETS, since their VS revealed to be low. Therefore, the results confirm former research, where also no evidence for carbon leakage could be found (Dechezlepretre et al. (2019) and Naegele and Zaklan (2019). Overall, it can be pointed out that sectors classified as “cutting emission” industries had a lower VS (negative sign of the coefficient) and those that were allocated to the “polluting emission” category had a higher VS (pos. sign of the coefficient). The coefficient of the low-cost variable turns out as expected, since it has a negative sign in all specifications of the conducted regression.

By introducing sector fixed effects, the impact of the coefficient turns out to be even stronger. Consequently, the sector fixed effects methods have a controlling influence on average differences across sectors. As a result, the fixed effect coefficients absorb the across-group action and therefore reduces the threat of omitted variable bias. Furthermore, the inclusion of control variables weakened the effect, since adding more independent variables to the regression lowers the probability of omitted variables bias and therefore lowers the value of the coefficient. In addition, only the control variables CI, TI and the log of employment had an impact on the VS, if very low. The quadratic forms of CI and TI turned out to be irrelevant.

If the same regression with the VS that indicates 0% of free emission certificates is conducted, the results still hold. The coefficient of the treatment variable shows the same development as in the case were 80% emission certificates are issued for free. This finding supports even more the conclusion that no evidence for carbon leakage could be found. However, it must be mentioned that most of the coefficients (except for one) got insignificant if 0% of the certificates were issued for free.

To conclude the analysis two different robustness checks were performed. Overall, it proves that the baseline estimates are not sensitive to changes of classification or specification in terms of treatment (low-cost variable). However, the heterogeneity test of the low-cost variable revealed an unexpected result: the coefficient of the ninth increment and tenth increment (polluting entities) were expected to be positive but turned out to be negative. This result can mainly be explained by the type of sector in this range. The 9^{th} increment is characterized mainly by Chemical & Plastic and the 10^{th} increment by Other Basic Metals. Both sectors have on average a VS of 1. Therefore, in every sector the amount of reduction in emissions cannot be linked to the relocation risk, since even sectors that are considered as emission-intensive are not necessary at risk of carbon leakage. This assumption suggests that besides the emission intensity, other factors must influence the relocation risk.

In terms of the second heterogeneity test on the sector/country level, the effects of the individual subjects wholly cancel each other out on estimation of the "average" effect. However, it is noticeable that the robustness check revealed that on industry level the effect was driven by Ceramics, therefore is larger for this industry. On a country level, Hungary has a larger effect than other countries: the impact is greater for this country.

7. Discussion

This study analyses whether abatement costs of European manufacturing sectors under the EU ETS have an impact on the relocation risk and therefore cause carbon leakage. In the following the results of the analysis as well as possible shortcomings of those are discussed. Moreover, limitations imposed on the study as a result of the chosen strategy are identified and attainable improvements of the model are formulated. Finally, the contribution to existing literature as well as implications for further research are presented.

7.1 Discussion of the Results

The analysis assumes that if the correlation turns out to be positive, low abatement costs are associated with low relocations cost, and therefore low-cost firms are exposed to carbon leakage, and are likely to leave the EU ETS first. Logically, in the opposite case, if the correlation between relocation costs and abatement costs is negative, the high-cost firms are the first to move out of the EU Cap and Trade Zone. The results show a negative correlation between abatement cost and relocation risk and therefore those that are cutting pollution are not at risk of carbon leakage. Since the correlation seems to be rather weak, it can be assumed that the medium-cost firms leave the EU Trading System first (Ahlvik & Liski, 2017). All assumptions made in this paper are based on the case that the sectors under study are getting 80% permits for free, as the objective of the EU ETS Scheme in 2030 is to distribute 100% of permits free of costs. To check the results, the same test was applied on the case where companies get no (0%) free permits to cover their emissions. It turns out that the sign of the coefficient does not change. This supports the assumption of the existence of no carbon leakage risk at those companies that are cutting emissions. However, most of the coefficients for the case of no (0%) free permits, turned out to be insignificant, which limits the validity of the results.

Furthermore, a robustness check was conducted which revealed that the baseline estimates are not sensitive to changes in the classification or specification of the treatment variable (low-cost variable). Nevertheless, the robustness checks also reveal the occurrence of certain conspicuous features occurring in some increment, for example it turned out that two third of the sectors located in France are considered as “cutting emissions” sectors based on the median calculation in this study. The opposite applies to the UK, where the same sectors are acknowledged as "polluting emissions" sectors (see Appendix A10). This could be an indication of sector related characteristics for example as whether "green technologies" are implemented on the level of production and demand, but country specific characteristics like political incentives that support the cut of emissions could also play a role. Moreover, the heterogeneity test of the "low-cost variable" revealed that the coefficient of some increments (that were expected to be positive, since they were associated with intense CO_2 emissions) turned out to be negative. It can be concluded that besides the level of abatement costs other aspects play a substantial role in the determination of relocation risk. Some of those aspects are highlighted in more detail in the next section in connection with a brief overview of further limitations to the data set and the chosen strategy, that need to be considered if interpreting the results.

7.2 Limitation to the Data Set & to the Estimation Strategy

The EU ETS Viewer provides an easy access to the emissions trading data contained in the EU Transaction Log (EUTL). It compares data at a country level, for example, data for CO_2 emissions for the United Kingdom and Germany can be compared with each other. The comparison is based on the Commission's assessment at aggregated EU level. The purpose of the introduction of fixed effects was to capture inter-industry and inter-country differences, since the exposure to carbon leakage vary due to different production methods, technologies and fuel blends (Sato et al., 2015). However, the data does not allow to control for factors such as the availability and implementation of new technologies. Also changes in demand as well as the respective market share across Europe are not taken into consideration when comparing countries and sectors with each other. Therefore, the chosen strategy of the median calculation which is based on a marginal percentage change analysis only expresses the reduction or the increase of emissions, but it doesn't give an explanation why. Furthermore, political changes between the different phases of the EU ETS as well as global economic events such as the financial crisis in 2007 or other global changes in demand and supply for manufacturing products were not considered in the analysis. In order to explain some of the differences within the countries it would be necessary to have a deeper look at sectoral characteristics in combination with political and economic condition in each country.

Nevertheless, preliminary statements can be noted about some findings of the study. The sector Other Basic Metals, which consists mainly of the production of primary and secondary aluminum, recorded a very high increase of emissions (+2392%) from 2005- 2017. This development could be explained by the increase of the price and the demand of aluminum (Cassetta et al., 2018); Statista, 2019b). Additionally, the variation in amount of CO_2 emissions within the countries regarding Other Basic Metals could be caused by the fact that around 60% of the aluminum production in Europe is located in Germany and France (Foundry-planet.com, 2019). Hence those two countries record the highest amount of emissions in respect to this sector. Moreover, the total number of emissions needs to be considered, if interpreting the results. The total number of polluted emissions can vary enormously within different sectors, for instance, Other Basic Metals shows a very high increase in the CO_2 emissions, but Fuels emitted 142 times more CO_2 (34,608 tons vs. 4915,233 tons CO_2) in the same time period. Consequently, factors that could explain the differences like market related characteristics are not considered, which leads to a decrease of the comparability between sectors and countries.

Not only the data set of the EU ETS data reviewer shows limitations but also the one provided by Martin et al. (2014a) shows problems, briefly described below, in respect to the validity of the results. First, in this study no information about pollution intensity is considered. It might occur that some sectors are more pollution intensive by nature than others and therefore are more likely to be exposed to carbon leakage. However, such a categorization was not made in this paper. In addition, some sectors needed to be excluded due to a lack of data availability, which constraints the number of sectors under study. For the remaining sectors, no indication could be found that the number of interviewed companies of the respective sectors represents the bulk of the overall pollution in the respective countries. A big difference in the amount of companies interviewed between sectors appeared, for example, the data set includes values for 46 interviewed companies from the Cement sector vs just 3 for companies of the Ceramic sector. Consequently, some sectors such as Ceramics, Other Basic Metals and Other Minerals are underrepresented in this study. It can be said that the final sample of 244 studied companies is far too small and not chosen randomly enough which may likely have led to insignificant results. This has not been considered in this paper. As a result, instead of formulating proven solid statements, indications are rather given.

Another problem that arises is the limited combinability of both data sets. The companies interviewed from Martin et al. (2014a) are medium-sized companies, limited by the number of employees (more than 50, less than 5,000). This distinction cannot be made in the EU ETS Data Viewer, which is why the two data sets can only be compared to a limited extent.

Although the possibility in the EU ETS Data Viewer is given to divide entities into different sizes based on the amount of emissions (see Appendix Table A8), there is no uniform basis for a subdivision when comparing the two datasets. Moreover, the classification of the entities in different sizes made by the EUTL are just estimates, since it does not contain information on the size of a unit. Instead, they use the maximum amount of emissions of an entity over the time series to determine their size (European Environment Agency, 2018b).

Overall, the data collection process showed how difficult and challenging it can be to obtain reliable and verifiable data as the problem of asymmetric information is inherent between the regulator and the companies. As already mentioned, the analysis led to the presumption that country-specific or sector-specific characteristics could also influence the relocation risk and therefore is not only explained by abatement costs. The following gives a brief overview of possible factors that could be included in future estimations in order to improve the model.

7.3 Possible Alternative Models

A possible improvement to the model could be inclusion of barriers that are preventing leakage, which are often bigger than emission costs such as tariffs and transportation costs of different sectors (Naegele & Zaklan, 2019). Furthermore, the ability of companies to pass through some of their emission costs to the final customer should be considered as well since this contribute to the lower cost of CO_2 emissions (Naegele & Zaklan, 2019). Often, the availability of innovative and green technologies as well as political incentives to implement those also determine the level of CO_2 emissions. In this connection, Sato et al. (2014) emphasizes sector specific features such as differences in production processes, technologies & fuel mix, process emissions, recycling rate differences, product mix differences, sector classifications that should be included in the design of future models. Furthermore, trade between EU member states plays a significant role in determining relocation risk since trade influences the size of the domestic market (Sato et al., 2014). In a broader perspective, diluting factors such as political risks in the new host country, exchange rate uncertainties, and the availability of qualified labor could improve the model. It can be concluded that intra-sectoral differences as well as intra-country differences could play a not negligible role in the assessment of relocation risk. Nevertheless, the results of this study contribute to the current research and gives implication for future research, which are briefly described below.

7.4 Theoretical Implications

As the literature research chapter shows, relocation risk and abatement costs have so far been small compared to each other. Some recent literature postulate that there a many factors besides low carbon prices and free allocation of certificates that influences the risk of relocation. Ederington et al. (2005) for example showed that some sectors are more "footloose" than others, so transport costs need to be considered if estimating the risk of carbon leakage. In other words, industries where high transport costs exist, are relatively protected from foreign competition. From Sato et al. (2014) it can be deducted that sectors at risk of carbon leakage are dependent on many parameters, one being the differences in production processes between sectors.

Although abatement costs are one of many factors - but not the least negligible - influencing the company's relocation risk, very little research has been conducted about the impact of abatement costs on relocation risks, mainly due to the given information asymmetry between regulator and regulated company.

This study has developed a strategy to assess avoidance costs. However, the generalizability of the results is restricted by numerous limitations that have been described above. Future research should focus on avoidance costs in relation to other factors that influence the relocation risk to be able to provide more precise statements about the risk of carbon leakage. A study that would have included all those factors would have far exceeded the scope of this work.

The study in this paper is based on findings from previous studies. The sign of the correlation between abatement costs and relocation risks has never been investigated before. The results of the analysis suggest that those companies that are cutting emissions are not exposed to carbon leakage. This finding confirms the results of previous research where no evidence for carbon leakage had been found. Another striking result of the study is that no difference in the effect could be found between an 80% and a 0% cost free issuance of certificates. Another proof that the allocation mechanism of CO_2 certificates is flawed. As Martin et al. (2014) already suggests, governments should rather spend money on infrastructure and R&D. Those investments are costly but indispensable for the transition to a low carbon company. The money is better off in such investments than in the unspecific subsidy of industries.

7.5 Managerial Implications

The results of this thesis revealed a number of new challenges associated to strategic and operational decisions of companies and in respect to the allocation mechanism of the EU ETS. Implications for improvement on a managerial level as well as on an EU-ETS level will be given in the following.

On a company level

Future events and their effects on environmental costs are uncertain, thus companies can barely predict economical risks. Relocation is risky and comes with costs, since the new host region could also imply equivalent policies in the future. Besides moving production sites abroad, companies can also choose to reduce emissions in order to reduce costs. The amount of emissions reduction strongly depends on the combination of various parameters such as the availability of innovative and greener technologies and market growth for example. Because many distinctive factors play a role, it will be difficult for companies to successfully incorporate and allow for an ecological variable in decisions in terms of corporate environmental strategies. Nevertheless, the importance of environmental problems and the trend of integrating those into the managerial decisions makes a sustainability consciousness more important than ever. As consumer purchasing decisions are more and more influenced by an environmental awareness, the implementation of "green technologies" do become a competitive factor that impacts corporate strategies (Coddington, 1992). This development can be seen for example already in the food industry, in the energy sector as well as in the automotive business (Belz & Schmidt-Riediger, 2009).

Historically firms have adapted ecological practices in order to meet legislative requirements and environmental guidelines. The implementation and establishment of “green” technologies initiated by the companies themselves is a very young development (Paulraj, 2008). Companies that cooperate in pollution intensive sectors should re- examine the impact of their environmental strategies, including an assessment of currently used technologies, the ways of producing their products as well as the level of awareness of sustainability issues, including the level of knowledge about low carbon innovations. Former research showed that an increase of information on environmental issues will lead a greater willingness of the consumer to pay for more environmentally friendly alternatives (Vespermann & Wittmer, 2011). This approach should be followed in terms of the set-up of incentives that support the implementation of low carbon technologies, which would reward environmental leaders in the long term for example in form of cost savings.

EU ETS level

Based on the results of this and previous research, the ETS should change and improve the ETS allocation mechanism and therefore provide strategic and operational implications for sectors in order to reduce their emissions. Previous research showed that the general public support goes towards the principle the "polluter pays", which implies that polluter takes responsibility for the environmental cost related to its pollution activities (Hammar & Jagers, 2007). Therefore, the EU ETS should develop a strategy that includes the distribution of emission costs according to the level of pollutions. Since the results of the study showed that the risk of relocation barely exists, this strategy should not depend on the risk of carbon leakage. A global and comprehensible framework should be achieved that include the agreement of all major emitters. As long as there is uniform scheme, companies will continue to face different carbon constraints in different countries even though many member states of the EU try to set long-term targets in order to provide predictability (Egenhofer, 2007). Therefore, companies should get informed on carbon risks and at the same time opportunities should be given in order to guide their future investments decisions forward to the implementation of greener and innovative technologies. As Martin et al. (2014b) already suggests, governments should rather spend money on infrastructure and R&D than on unspecific subsidies of industries. Therefore, such investments will be costly but indispensable in order to set up mechanism that support pollution intensive sectors to meet innovation challenges towards to a low carbon economy.

8. Conclusion

This thesis went on to explicitly investigate the research question *"Is there a correlation between abatement costs and relocation risk across different industries (footloose vs. non - footloose) under the EU ETS Scheme?"* To answer the question at hand, a fixed effects analysis was conducted to compute the impact of the abatement costs on potential relocation risks. Data at firm level were utilized and combined with macro level data from the EU ETS, which was used to classify subjects in "polluting" and "cutting emission" entities, and therefore overcome the information asymmetry between regulator and regulated entity.

Indications that companies with low abatement costs are associated with low relocation risk if 80% of the permits issued were free of costs have been confirmed by this study. Thus, the validation of the second hypotheses posited in chapter 3.6. Moreover, no evidence of carbon leakage could be found, thus supporting findings of prior studies. It is also noticeable that at the industry level Ceramics, being a dominant player, highly contributes to this result. On a country level higher effects on Hungary could be determined, more than on any other European country. Robustness checks revealed that none of those tests changed the estimated baseline results considerably.

This supports former research where no evidence for relocation has been observed. An explanation for the lack of evidence of carbon leakage could be that the relocation risks for sectors or industries with already low abatement costs is too low (investigated in form of interview-based Vulnerability Scores of managers) to assume a serious relocation of these companies outside of the EU due to more stringent environmental policies.

However, the estimation strategy used cannot affirm the causal effect of the EU ETS on leakage, as it cannot be ruled out that region-specific productivity changes, political sectoral characteristics and changes in political and economic conditions might upset the expectations of the EU ETS. If policymakers aim at significant emission reductions within emission intensive industries, a more accurate system will have to be designed. It will foremost have to revise the allocation criteria and the incentives to implement greener technologies. At the company level, the EU ETS system in fact acknowledges managerial challenges, including strategic and operational decisions involved in emission monitoring.

I hope that this thesis will contribute to the already done research.

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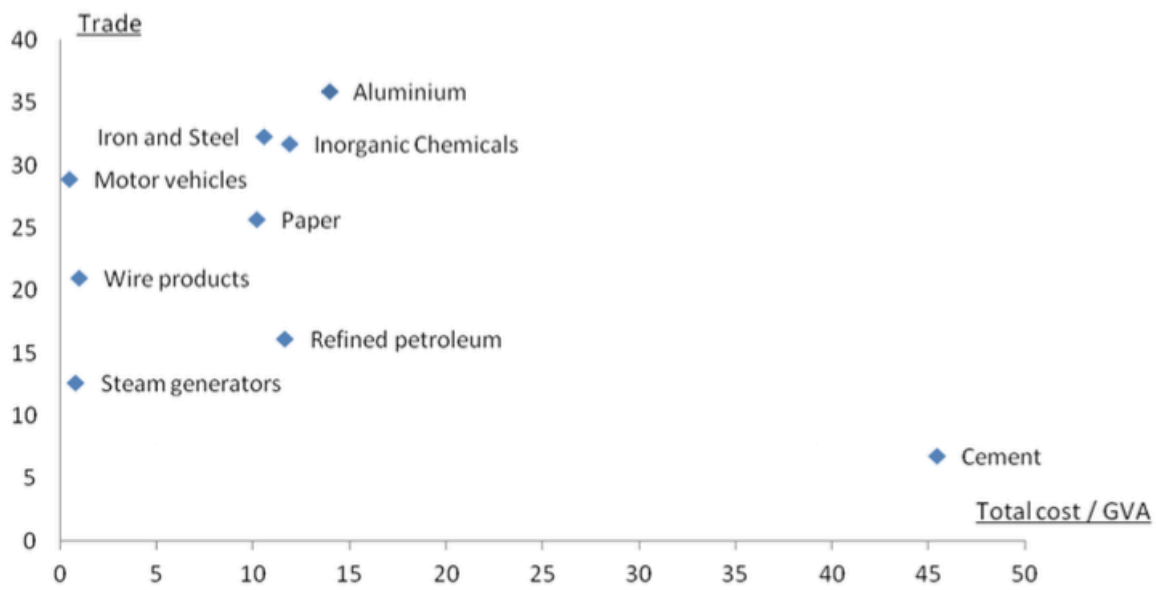
Appendix

A1 Criteria and sectors at risk

Figure A1: Selection of sectors plotted by trade exposure and total ETS costs/GVA



Note: Sectors at NACE-4 code level. Illustration extracted from Marcu, et al. (2013)

A2: Descriptive Statistics of the interview data set (Online Appendix) provided by Martin et al. (2014b)

Table A1: Sample representativeness

	(1) Turnover	(2) Employment	(3) Capital
A. All firms			
Firm contacted	-0.0322	-0.0794	0.172
	(0.0786)	(0.0611)	(0.108)
EU ETS firm	2.031***	1.452***	2.530***
	(0.095)	(0.080)	(0.145)
Number of observations	118,874	107,830	113,771
Number of firms	12,322	12,921	118,874
R-squared	0.511	0.364	12322
B. Contacted firms			
Firm granted interview	-0.0983	-0.0373	0.0443
	(0.118)	(0.0957)	(0.150)
EU ETS firm	2.044***	1.547***	2.540***
	(0.124)	(0.107)	(0.160)
Number of observations	26,114	23,933	25,815
Number of firms	1,373	1,420	1,297
R-squared	0.659	0.589	0.618

"Notes: Regressions in panel A are based on the set of manufacturing firms with more than 50 employees contained in ORBIS for the six countries covered by the survey. Each column shows the results from a regression of the ORBIS variable given in the column head on a dummy variable indicating whether a firm was contacted or not and a dummy variable indicating whether a firm was taking part in the EU ETS at the time of the interviews. Panel B shows analogous regressions for the set of contacted companies and with an indicator for whether an interview was granted. All regressions are by OLS and include country dummies, year dummies and 3-digit sector dummies. Standard errors are clustered at the firm level and are robust to heteroskedasticity and autocorrelation of unknown form. * significant at 10%; ** significant at 5%; *** significant at 1%." Martin et al. (2014b).

Table A2: Interview response rates by country

	# of Interviews	# of Firms Interviewed	# of ETS Firms Interviewed	# of Non ETS Firms Interviewed	Total Firms Contacted	Refused	Response Rate
Belgium	134	131	85	46	178	47	0.74
France	141	140	92	48	238	98	0.59
Germany	139	138	95	43	337	199	0.41
Hungary	69	69	37	32	90	21	0.77
Poland	78	78	57	21	140	62	0.56
UK	209	205	63	142	468	264	0.44
Total	770	761	429	332	1451	691	0.52

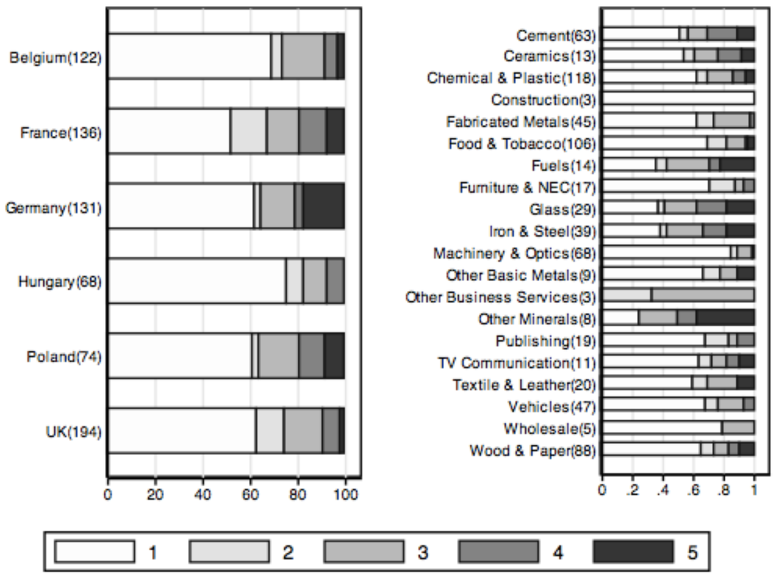
Note: More interviews than interviewed firms are displayed conducted several interviews with different partners in a small number of firms. Table extracted from Martin et al. (2014b)

Table A3: Firm characteristics by ETS participation status

	ETS Firms			non ETS Firms		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Firm						
Age (years) *	40	37	409	33	37	327
Turnover (EUR million) **	725.73	3,611.50	398	146.42	767.93	298
Number of employees **	1,418	5,092	394	469	857	305
EBIT (EUR million) **	26.12	100.54	391	5.22	23.47	292
Number of shareholders	2	5	429	3	5	332
Number of subsidiaries	6	32	429	2	5	332
Firm's Global Ultimate Owner						
Turnover (USD million)	31,695	67,080	142	12,464	21,980	99
Number of employees	50,012	71,864	131	42,381	73,834	95

"Notes: Based on 2007 data. Stars next to a variable name indicate that the respective means for ETS and non ETS firms are significantly different at the 10% (*), 5% (**), and 1% (***) levels." (Martin et al. (2014b)

Figure A2: Distribution of vulnerability score by country and industry



"Notes: Bar charts show the distribution of the vulnerability score by country (left) and by 3-digit NACE sector (right). The score ranges from 1 (no impact) to 5 (complete relocation). A score of 3 is given if at least 10% of production or employment would be outsourced in response to future carbon pricing. The number of observations in each country and industry is given in parenthesis. NEC: Not elsewhere classified." Martin et al. (2014b).

Table A4: Descriptive statistics of the Vulnerability Score

	Mean	Standard deviation	Min	P25	Median	P75	Max	Firms
Overall vulnerability score	1.87	1.29	1	1	1	3	5	725
A. by country								
Belgium	1.69	1.13	1	1	1	3	5	122
France	2.07	1.34	1	1	1	3	5	136
Germany	2.12	1.58	1	1	1	3	5	131
Hungary	1.50	0.95	1	1	1	2	4	68
Poland	2.03	1.40	1	1	1	3	5	74
UK	1.75	1.12	1	1	1	3	5	194
B. by 3-digit sector								
Cement	2.33	1.52	1	1	1	4	5	63
Ceramics	2.15	1.46	1	1	1	3	5	13
Chemical & Plastic	1.86	1.26	1	1	1	3	5	118
Construction	1.00	0.00	1	1	1	1	1	3
Fabricated Metals	1.67	0.93	1	1	1	3	4	45
Food & Tobacco	1.56	1.01	1	1	1	2	5	106
Fuels	2.71	1.59	1	1	3	4	5	14
Furniture & NEC	1.47	0.87	1	1	1	2	4	17
Glass	2.76	1.57	1	1	3	4	5	29
Iron & Steel	2.69	1.56	1	1	3	4	5	39
Machinery & Optics	1.26	0.68	1	1	1	1	4	68
Other Basic Metals	1.78	1.39	1	1	1	2	5	9
Other Business Services	2.67	0.58	2	2	3	3	3	3
Other Minerals	3.38	1.69	1	2	4	5	5	8
Publishing	1.58	1.02	1	1	1	2	4	19
TV Communication	1.91	1.45	1	1	1	3	5	11
Textile & Leather	1.90	1.33	1	1	1	3	5	20
Vehicles	1.62	0.99	1	1	1	2	4	47
Wholesale	1.40	0.89	1	1	1	1	3	5
Wood & Paper	1.85	1.36	1	1	1	3	5	88

"Notes: Summary statistics of the overall vulnerability score (first row), by country (panel A) and by 3-digit NACE sector (panel B). The score ranges from 1 (no impact) to 5 (complete relocation). A score of 3 is given if at least 10% of production of employment would be outsourced in response to future carbon pricing. NEC: Not elsewhere classified." Martin et al. (2014b).

A3: Description of data set from the European Environment Agency

Table A5: EU TL activity type

Activity type code	Activity
10	Aviation
20	Combustion of fuels
21	Refining of mineral oil
22	Production of coke
23	Metal ore roasting or sintering
24	Production of pig iron or steel
25	Production or processing of ferrous metals
26	Production of primary aluminium
27	Production of secondary aluminium
28	Production or processing of non-ferrous metals
29	Production of cement clinker
30	Production of lime, or calcination of dolomite/magnesite
31	Manufacture of glass
32	Manufacture of ceramics
33	Manufacture of mineral wool
34	Production or processing of gypsum or plasterboard
35	Production of pulp
36	Production of paper or cardboard
37	Production of carbon black
38	Production of nitric acid
39	Production of adipic acid
40	Production of glyoxal and glyoxylic acid
41	Production of ammonia
42	Production of bulk chemicals
43	Production of hydrogen and synthesis gas
44	Production of soda ash and sodium bicarbonate
45	Capture of greenhouse gases under Directive 2009/31/EC
46	Transport of greenhouse gases under Directive 2009/31/EC
47	Storage of greenhouse gases under Directive 2009/31/EC
99	Other activity opted-in pursuant to Article 24 of Directive 2003/87/EC
20-99	All stationary installations
21-99	All inductrial installations

Note: extracted from European Environment Agency (2019a)

Table A6: Activities and sectors covered by the EU ETS 2017

Activities	**Sectors**	**Number of entities**	**Verified emissions Mt CO_2-eq**
20 Combustion of fuels	Combustion	7496	1,101
21 Refining of mineral oil	Refineries	139	125
22 Production of coke	Iron and Steel, coke, metal ore	20	11
23 Metal ore roasting or sintering		9	3
24 Production of pig iron or steel		246	108
25 Production or processing of ferrous metals	Other metals (incl. aluminium)	250	13
26 Production of primary aluminium		33	9
27 Production of secondary aluminium		33	1
28 Production or processing of non-ferrous metals		91	8
29 Production of cement clinker	Cement and Lime	259	120
30 Production of lime, or calcination of dolomite/magnesite		299	32
31 Manufacture of glass	Other non-metallic minerals	372	18
32 Manufacture of ceramics		1087	15
33 Manufacture of mineral wool		52	2
34 Production or processing of gypsum or plasterboard		40	1
35 Production of pulp	Pulp and Paper	179	6
36 Production of paper or cardboard		585	22
37 Production of carbon black	Chemicals	18	2
38 Production of nitric acid		37	4
39 Production of adipic acid		3	0
40 Production of glyoxal and glyoxylic acid		1	0
41 Production of ammonia		29	21
42 Production of bulk chemicals		364	38
43 Production of hydrogen and synthesis gas		42	8
44 Production of soda ash and sodium bicarbonate		14	3
45 Capture of greenhouse gases under Directive 2009/31/EC	Other	2	0
46 Transport of greenhouse gases under Directive 2009/31/EC		1	0
99 Other activity opted-in under Art. 24		257	1
Sum of all stationary installations		**11,958**	**1,673**
10 Aviation		525	67

Note: extracted from European Environment Agency (2019a)

Table A7: Total Number of Emissions in the years 2005 - 2017

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Overall result	Average of Emissions (2005-2011)	Average of Emissions (2012-2017)	Averge Change (Average 2012-2017 / Average 2005-2011)
Belgium	55,363	54,777	52,795	55,462	46,209	50,104	46,203	43,006	45,231	43,851	44,715	43,655	43,772	625,143	51,559	44,03833333	0,854134745
Cement	8,124	8,499	8,286	8,03	6,436	6,675	6,984	6,632	6,456	6,628	6,116	6,087	5,822	90,775	7,576285714	6,290166667	0,83024412
Ceramics	0,639	0,658	0,648	0,647	0,514	0,47	0,517	0,466	0,45	0,492	0,519	0,487	0,503	7,01	0,584714286	0,486166667	0,831460217
Chemical & Plastic	3,57	3,572	3,347	5,834	5,152	5,739	5,735	5,65	8,661	8,51	8,884	8,516	9,056	82,226	4,707	8,212833333	1,74481269
Fuels	31,167	29,865	29,501	29,475	27,421	28,436	24,736	23,398	22,687	21,404	22,322	21,111	21,145	332,668	28,65728571	22,01116667	0,768082745
Glass	1,302	1,312	1,252	1,201	0,955	1,083	1,075	0,883	0,748	0,691	0,705	0,703	0,69	12,6	1,168571429	0,736666667	0,630399348
Iron & Steel	9,06	9,348	8,337	8,659	4,416	6,123	5,627	4,525	4,692	4,624	4,524	5,078	4,92	79,933	7,367142857	4,727166667	0,641655355
Other Basic Metals	0,696	0,699	0,665	0,855	0,607	0,753	0,719	0,653	0,773	0,755	0,826	0,85	0,873	9,724	0,713428571	0,788333333	1,104992658
Other Minerals	0,062	0,063	0,063	0,061	0,067	0,057	0,052	0,041	0,041	0,04	0,039	0,047	0,051	0,684	0,060714286	0,043166667	0,710980392
Wood & Paper	0,743	0,761	0,696	0,7	0,641	0,768	0,758	0,758	0,723	0,707	0,78	0,776	0,712	9,523	0,723857143	0,742666667	1,025985133
France	131,246	126,961	126,617	124,125	111,093	115,543	105,574	103,66	114,549	100,23	99,6	101,613	106,763	1467,574	120,1655714	104,4025	0,868822066
Cement	17,334	17,824	18,049	16,905	14,344	14,999	15,362	14,432	14,497	13,844	12,921	12,945	12,532	195,988	16,40242857	13,5285	0,824786399
Ceramics	0,989	1,026	1,025	0,898	0,737	0,777	0,859	0,744	0,779	0,753	0,716	0,717	0,73	10,75	0,901571429	0,739833333	0,820604236
Chemical & Plastic	1,412	1,325	1,296	1,668	1,442	1,23	1,189	1,178	4,15	4,3	4,152	4,133	4,128	31,603	1,366	3,6735	2,689238653
Fuels	77,235	71,999	72,609	74,229	72,07	71,908	62,649	62,054	69,366	55,696	57,247	59,703	63,896	870,661	71,81414286	61,327	0,853968279
Glass	3,602	3,553	3,494	3,226	2,76	2,817	2,947	2,668	2,51	2,472	2,502	2,472	2,495	37,518	3,199857143	2,519833333	0,787483072
Iron & Steel	26,429	27,257	26,505	23,967	17,019	20,982	20,013	19,827	17,671	17,534	16,608	15,954	17,412	267,178	23,16742857	17,501	0,755414005
Other Basic Metals	0,518	0,504	0,499	0,496	0,369	0,351	0,377	0,433	2,929	3,031	2,984	3,22	3,15	18,861	0,444857143	2,6245	5,899646757
Other Minerals	0,007	0,007	0,006	0,006	0,011	0,015	0,018	0,023	0,311	0,289	0,287	0,287	0,301	1,568	0,01	0,249666667	24,96666667
Wood & Paper	3,72	3,466	3,134	2,73	2,341	2,464	2,16	2,301	2,336	2,311	2,183	2,182	2,119	33,447	2,859285714	2,238666667	0,782946124
Germany	475,052	478,075	487,147	472,854	428,294	454,863	450,352	452,593	481,043	461,299	455,78	452,868	437,623	5987,843	463,8052857	456,8676667	0,985041958
Cement	29,81	30,428	32,381	30,6	27,174	27,954	29,793	29,228	28,345	28,97	28,312	28,427	29,811	381,233	29,73428571	28,84883333	0,970221165
Ceramics	1,807	1,877	1,865	2,887	2,771	2,685	2,663	2,481	2,132	2,061	1,988	2,025	2,041	29,283	2,365	2,121333333	0,896969697
Chemical & Plastic	0,873	0,788	0,793	6,536	5,845	6,348	6,291	6,098	18,381	18,099	17,779	18,187	18,037	124,055	3,924857143	16,09683333	4,101253306
Fuels	403,512	404,674	410,983	391,368	360,126	379,052	372,882	377,426	387,262	366,788	361,391	358,828	340,941	4915,233	388,9424286	365,4393333	0,939571789
Glass	3,951	3,972	4,027	3,925	3,644	3,811	3,824	3,637	3,714	3,792	3,775	3,826	3,74	49,638	3,879142857	3,747333333	0,966020967
Iron & Steel	27,749	28,99	29,8	29,95	22,027	27,919	28,163	27,324	28,386	28,912	29,815	28,891	30,164	368,09	27,79971429	28,91533333	1,040130594
Other Basic Metals	0,106	0,114	0,094	0,382	0,233	0,316	0,303	0,439	6,495	6,499	6,501	6,51	6,616	34,608	0,221142857	5,51	24,91602067
Other Minerals				0,335	0,32	0,356	0,374	0,34	0,616	0,62	0,632	0,641	0,655	4,889	0,34625	0,584	1,686642599
Wood & Paper	7,244	7,232	7,204	6,871	6,154	6,422	6,059	5,62	5,712	5,558	5,587	5,533	5,618	80,814	6,740857143	5,604666667	0,831447181
Hungary	26,162	25,846	26,836	27,236	22,401	22,993	22,47	21,265	19,133	18,816	19,65	19,401	20,642	292,851	24,84914286	19,81783333	0,797525832
Cement	1,884	1,944	2,029	1,971	1,393	1,073	1,153	1,295	0,988	1,074	1,269	1,268	1,466	18,807	1,635285714	1,226666667	0,750123759
Ceramics	0,997	0,937	0,948	0,819	0,483	0,502	0,468	0,399	0,266	0,229	0,249	0,287	0,314	6,898	0,736285714	0,290666667	0,394774285
Chemical & Plastic	0,071	0,073	0,103	1,378	1,247	1,407	1,406	1,159	2,082	2,324	2,289	2,234	2,495	18,268	0,812142857	2,097166667	2,582263266
Fuels	21,117	20,872	21,73	21,08	17,681	18,25	17,629	16,706	14,479	13,739	14,235	14,31	14,343	226,171	19,76557143	14,63533333	0,740445749
Glass	0,271	0,285	0,285	0,259	0,223	0,216	0,213	0,208	0,2	0,21	0,201	0,207	0,207	2,985	0,250285714	0,2055	0,821061644
Iron & Steel	1,471	1,397	1,432	1,41	1,121	1,229	1,263	1,146	0,685	0,855	1,114	0,811	1,141	15,075	1,331857143	0,958666667	0,719796918
Other Basic Metals	0,219	0,217	0,193	0,19	0,135	0,162	0,176	0,191	0,264	0,235	0,225	0,215	0,233	2,655	0,184571429	0,227166667	1,230779154
Other Minerals	0,006	0,003	0,002	0,019	0,02	0,022	0,027	0,025	0,026	0,026	0,029	0,028	0,028	0,261	0,014142857	0,027	1,909090909
Wood & Paper	0,126	0,118	0,114	0,11	0,098	0,132	0,135	0,136	0,143	0,124	0,039	0,041	0,415	1,731	0,119	0,149666667	1,257703081
Poland	203,149	209,618	209,619	204,11	191,174	199,727	203,026	196,636	205,735	197,129	198,7	198,052	202,167	2618,842	202,9175714	199,7365	0,984323332
Cement	10,608	12,297	14,234	12,951	10,995	11,784	13,944	12,047	11,114	12,03	11,847	12,127	12,854	158,832	12,40185714	12,00316667	0,967852357
Ceramics	1,165	1,167	0,731	0,689	0,544	0,546	0,529	0,441	1,035	0,97	0,988	1,035	1,086	10,926	0,767285714	0,925833333	1,206634395
Chemical & Plastic	0,163	0,136	0,154	0,978	0,932	0,909	0,978	0,952	6,935	7,012	7,251	7,142	7,345	40,887	0,607142857	6,106166667	10,05721569
Fuels	182,607	186,308	184,622	178,281	170,782	177,207	177,451	173,169	175,42	165,449	166,651	165,849	168,236	2272,032	179,6082857	169,129	0,941654776
Glass	1,438	1,431	1,467	1,462	1,19	1,287	1,475	1,511	1,524	1,529	1,504	1,584	1,65	19,052	1,392857143	1,550333333	1,113059829
Iron & Steel	5,368	6,567	6,729	6,972	4,204	5,178	5,559	5,394	4,931	5,439	5,544	5,344	5,791	73,02	5,796714286	5,407166667	0,932798548
Other Basic Metals	0,023	0,025	0,019	1,058	0,749	0,807	0,851	0,823	2,08	2,184	2,272	2,332	2,8	16,023	0,504571429	2,081833333	4,125943752
Other Minerals				0,23	0,201	0,225	0,241	0,263	0,372	0,364	0,336	0,372	0,441	3,045	0,22425	0,358	1,596432553
Wood & Paper	1,777	1,687	1,663	1,489	1,577	1,784	1,998	2,036	2,324	2,152	2,307	2,267	1,964	25,025	1,710714286	2,175	1,271398747
United Kingdom	242,502	251,146	256,568	264,763	231,744	237,182	220,716	231	225,305	197,749	175,607	147,132	136,727	2818,141	243,5172857	185,5866667	0,762108801
Cement	5,482	5,441	9,117	10,899	7,738	7,986	8,329	7,742	8,415	8,725	9,014	9,047	8,967	106,902	7,856	8,651666667	1,101281399
Ceramics	0,137	0,127	0,187	1,004	0,65	0,759	0,78	0,72	0,531	0,589	0,584	0,588	0,603	7,259	0,520571429	0,6025	1,157381998
Chemical & Plastic	1,341	1,283	1,265	3,203	2,938	3,066	3,071	2,945	5,447	4,762	4,948	4,782	5,109	44,16	2,309571429	4,6655	2,020071751
Fuels	222,109	230,578	231,852	232,715	206,663	213,598	197,975	207,079	193,218	165,283	145,409	122,219	111,494	2480,192	219,3557143	157,4503333	0,717785419
Glass	0,315	0,357	0,314	1,438	1,17	1,276	1,39	1,294	1,282	1,266	1,245	1,268	1,294	13,909	0,894285714	1,274833333	1,425532481
Iron & Steel	6,39	6,862	7,372	7,163	5,453	7,487	7,312	9,262	13,877	14,62	11,942	6,882	6,879	111,501	6,862714286	10,577	1,54122692
Other Basic Metals	6,433	6,287	6,264	6,279	5,463	1,242	0,101	0,096	0,638	0,67	0,627	0,598	0,629	35,327	4,581285714	0,543	0,118525679
Other Minerals	0,059	0,063	0,052	0,458	0,428	0,447	0,459	0,436	0,417	0,437	0,439	0,453	0,455	4,603	0,280857143	0,4395	1,564852492
Wood & Paper	0,236	0,148	0,145	1,604	1,241	1,321	1,299	1,426	1,48	1,397	1,399	1,295	1,297	14,288	0,856285714	1,382333333	1,614336559
Overall result	1133,474	1146,423	1159,582	1148,55	1030,915	1080,412	1048,341	1048,16	1090,996	1019,074	994,052	962,721	947,694	13810,394	1106,813857	1010,4495	0,912935354

Note: Data extracted from European Environmental Agency (2019b)

Table A8: Size Definition of entities in the EU ETS Data viewer

Size	Emission values
large	Entities with verified emissions higher than 500 000 t CO_2
medium	Entities with verified emissions comprised between 50 000 and 500 000 t CO_2
small	Entities with verified emissions comprised between 25 000 and 50 000 t CO_2
mini	Entities with verified emissions lower than 25 000 t CO_2
zero	Entities with verified emissions equal to 0
unknown	Entities where verified emissions are unknown
All sizes	All entities

Note: "The EUTL does not contain information on the size of an entity. As an approximation, the maximum emissions of an entity over the time series are used to define its size." Table and notes extracted from European Environment Agency (2019a)

A4: Results of the specification of sectors

Table A9: Results of the Median calculation

Country	Sector	Averge Change (Average 2012-2017 / Average 2005-2011)	Treatment	Change in %
Belgium	Cement	0,83024412	1	-17%
	Ceramics	0,831460217	1	-17%
	Chemical & Plastic	1,74481269	0	74%
	Fuels	0,768082745	1	-23%
	Glass	0,630399348	1	-37%
	Iron & Steel	0,641655355	1	-36%
	Other Basic Metals	1,104992658	0	10%
	Other Minerals	0,710980392	1	-29%
	Wood & Paper	1,025985133	0	3%
	Overall	0,854134745	1	-15%
France	Cement	0,824786399	1	-18%
	Ceramics	0,820604236	1	-18%
	Chemical & Plastic	2,689238653	0	169%
	Fuels	0,853968279	1	-15%
	Glass	0,787483072	1	-21%
	Iron & Steel	0,755414005	1	-24%
	Other Basic Metals	5,899646757	0	490%
	Other Minerals	24,96666667	0	2397%
	Wood & Paper	0,782946124	1	-22%
	Overall	0,868822066	1	-13%
Germany	Cement	0,970221165	1	-3%
	Ceramics	0,896969697	1	-10%
	Chemical & Plastic	4,101253306	0	310%
	Fuels	0,939571789	1	-6%
	Glass	0,966020967	1	-3%
	Iron & Steel	1,040130594	0	4%
	Other Basic Metals	24,91602067	0	2392%
	Other Minerals	1,686642599	0	69%
	Wood & Paper	0,831447181	1	-17%
	Overall	0,985041958	0	-1%
Hungary	Cement	0,750123759	1	-25%
	Ceramics	0,394774285	1	-61%
	Chemical & Plastic	2,582263266	0	158%
	Fuels	0,740445749	1	-26%
	Glass	0,821061644	1	-18%
	Iron & Steel	0,719796918	1	-28%
	Other Basic Metals	1,230779154	0	23%
	Other Minerals	1,909090909	0	91%
	Wood & Paper	1,257703081	0	26%
	Overall	0,797525832	1	-20%
Poland	Cement	0,967852357	1	-3%
	Ceramics	1,206634395	0	21%
	Chemical & Plastic	10,05721569	0	906%
	Fuels	0,941654776	1	-6%
	Glass	1,113059829	0	11%
	Iron & Steel	0,932798548	1	-7%
	Other Basic Metals	4,125943752	0	313%
	Other Minerals	1,596432553	0	60%
	Wood & Paper	1,271398747	0	27%
	Overall	0,984323332	0	-2%
UK	Cement	1,101281399	0	10%
	Ceramics	1,157381998	0	16%
	Chemical & Plastic	2,020071751	0	102%
	Fuels	0,717785419	1	-28%
	Glass	1,425532481	0	43%
	Iron & Steel	1,54122692	0	54%
	Other Basic Metals	0,118525679	1	-88%
	Other Minerals	1,564852492	0	56%
	Wood & Paper	1,614336559	0	61%
	Overall	0,762108801	1	-24%
All countries/sectors		0,912935354	1	1

Note: Median: 0,998103149; the overall results for each country were not included in the calculation of the median.

A5: Results from the Robustness Checks

Table A10: Robustness Check

Average Change	Sector	Country	Treatment	10% Increments
0,118525679	Other Basic Metals	United Kingdom	1	1
0,394774285	Ceramics	Hungary	1	1
0,630399348	Glass	Belgium	1	1
0,641655355	Iron & Steel	Belgium	1	1
0,710980392	Other Minerals	Belgium	1	1
0,717785419	Fuels	United Kingdom	1	2
0,719796918	Iron & Steel	Hungary	1	2
0,740445749	Fuels	Hungary	1	2
0,750123759	Cement	Hungary	1	2
0,755414005	Iron & Steel	France	1	2
0,768082745	Fuels	Belgium	1	2
0,782946124	Wood & Paper	France	1	3
0,787483072	Glass	France	1	3
0,820604236	Ceramics	France	1	3
0,821061644	Glass	Hungary	1	3
0,824786399	Cement	France	1	3
0,83024412	Cement	Belgium	1	4
0,831447181	Wood & Paper	Germany	1	4
0,831460217	Ceramics	Belgium	1	4
0,853968279	Fuels	France	1	4
0,896969697	Ceramics	Germany	1	4
0,932798548	Iron & Steel	Poland	1	4
0,939571789	Fuels	Germany	1	5
0,941654776	Fuels	Poland	1	5
0,966020967	Glass	Germany	1	5
0,967852357	Cement	Poland	1	5
0,970221165	Cement	Germany	1	5
1,025985133	Wood & Paper	Belgium	0	6
1,040130594	Iron & Steel	Germany	0	6
1,101281399	Cement	United Kingdom	0	6
1,104992658	Other Basic Metals	Belgium	0	6
1,113059829	Glass	Poland	0	6
1,157381998	Ceramics	United Kingdom	0	6
1,206634395	Ceramics	Poland	0	7
1,230779154	Other Basic Metals	Hungary	0	7
1,257703081	Wood & Paper	Hungary	0	7
1,271398747	Wood & Paper	Poland	0	7
1,425532481	Glass	United Kingdom	0	7
1,54122692	Iron & Steel	United Kingdom	0	8
1,564852492	Other Minerals	United Kingdom	0	8
1,596432553	Other Minerals	Poland	0	8
1,614336559	Wood & Paper	United Kingdom	0	8
1,686642599	Other Minerals	Germany	0	8
1,74481269	Chemical & Plastic	Belgium	0	8
1,909090909	Other Minerals	Hungary	0	9
2,020071751	Chemical & Plastic	United Kingdom	0	9
2,582263266	Chemical & Plastic	Hungary	0	9
2,689238653	Chemical & Plastic	France	0	9
4,101253306	Chemical & Plastic	Germany	0	9
4,125943752	Other Basic Metals	Poland	0	10
5,899646757	Other Basic Metals	France	0	10
10,05721569	Chemical & Plastic	Poland	0	10
24,91602067	Other Basic Metals	Germany	0	10
24,96666667	Other Minerals	France	0	10

Note: Treatment from the Median Calculation/(average 2012-2017/average 2005-2011)

Table A11. Robustness Checks on Sector Level

A: Descriptive Statistics of the variable (sector*low-cost variable)

Variable	Mean	SD	Min	Max	N
Iron & Steel	.074	.262	0	1	18
Chemical & Plastic	0	0	0	0	0
Wood & Paper	.135	.343	0	1	33
Cement	.148	.355	0	1	36
Glass	.049	.217	0	1	12
Other Basic Metals	0	0	0	0	0
Fuels	.037	.189	0	1	9
Other Minerals	0	0	0	0	0
Ceramics	.004	.064	0	1	1

Note: Each sector variable includes just values for cutting entities (low-cost variable = 1). The sector Chemical & Plastic is missing in the illustration, since it was in none of the countries classified as a "cutting emissions" sector and therefore the low-cost variable equals 0. The sectors Other Basic Metals and Other Minerals were declared as reducing sectors in the UK, but since no data on these sectors in the UK is available, they do not appear in the table.

B: Results of the regression without control variables (VS- 80% of the permits for free)

VS (ln)	Coef.	SD	t-value	p-value	[95% Conf.	Interval]	Sig
Iron & Steel	0.087	0.132	0.65	0.514	-0.174	0.347	
Chemical & Plastic	0.000	.	.	.	.	.	
Wood & Paper	-0.037	0.102	-0.36	0.719	-0.239	0.165	
Cement	-0.121	0.099	-1.22	0.223	-0.316	0.074	
Glass	-0.199	0.159	-1.25	0.211	-0.512	0.114	
Other Basic Metals	0.000	.	.	.	.	.	
Fuels	0.025	0.182	0.14	0.888	-0.332	0.383	
Other Minerals	0.000	.	.	.	.	.	
Ceramics	-0.373	0.529	-0.70	0.482	-1.415	0.670	

**** p<0.01, ** p<0.05, * p<0.1*

C: Results of the regression with control variables (VS- 80% of the permits for free)

VS (ln)	Coef.	SD	t-value	p-value	[95% Conf.	Interval]	Sig
Iron & Steel	0.077	0.154	0.50	0.615	-0.225	0.380	
Chemical & Plastic	0.000	.	.	.	.	.	
Wood & Paper	-0.003	0.105	-0.03	0.975	-0.211	0.204	
Cement	-0.283	0.119	-2.37	0.019	-0.519	-0.048	**
Glass	-0.217	0.132	-1.65	0.101	-0.477	0.042	
Other Basic Metals	0.000	.	.	.	.	.	
Fuels	-0.135	0.204	-0.66	0.508	-0.537	0.267	
Other Minerals	0.000	.	.	.	.	.	
Ceramics	-0.366	0.097	-3.77	0.000	-0.557	-0.175	***
Trade Intensity	-0.004	0.002	-1.50	0.134	-0.008	0.001	
Carbon Intensity	-0.005	0.014	-0.39	0.700	-0.033	0.022	
TI x TI	0.000	0.000	1.08	0.279	0.000	0.000	
CI x CI	0.000	0.000	0.81	0.416	0.000	0.000	
CI x TI	0.000	0.000	1.32	0.187	0.000	0.000	
Employment (ln)	0.003	0.028	0.11	0.912	-0.053	0.059	

**** p<0.01, ** p<0.05, * p<0.1*

Table A12. Robustness Check on Country Level

A: Descriptive Statistics of the variable (country*low-cost variable)

Variable	Mean	SD	Min	Max	N
Belgium	.086	.281	0	1	21
France	.164	.371	0	1	40
Germany	.049	.217	0	1	12
Hungary	.07	.255	0	1	17
Poland	.066	.248	0	1	16
UK	.012	.11	0	1	3

Note: Each sector variable includes just values for cutting entities (low-cost variable = 1).

B: Results of the regression without control variables (VS- 80% of the permits for free)

VS (ln)	Coef.	SD	t-value	p-value	[95% Conf	Interval]	Sig
Belgium	-0.125	0.123	-1.02	0.307	-0.367	0.116	
France	0.058	0.094	0.61	0.541	-0.128	0.243	
Germany	-0.055	0.157	-0.35	0.725	-0.366	0.255	
Hungary	-0.332	0.134	-2.47	0.014	-0.597	-0.067	**
Poland	-0.037	0.138	-0.27	0.791	-0.309	0.235	
UK	0.225	0.305	0.74	0.462	-0.376	0.825	

**** p<0.01, ** p<0.05, * p<0.1*

C: Results of the regression with control variables (VS- 80% of the permits for free)

VS (ln)	Coef.	SD	t-value	p-value	[95% Conf	Interval]	Sig
Belgium	-0.242	0.133	-1.81	0.071	-0.505	0.021	*
France	0.043	0.101	0.42	0.672	-0.156	0.242	
Germany	-0.023	0.172	-0.13	0.895	-0.362	0.317	
Hungary	-0.440	0.095	-4.63	0.000	-0.627	-0.253	***
Poland	-0.218	0.161	-1.36	0.176	-0.535	0.098	
UK	0.048	0.297	0.16	0.873	-0.538	0.633	
Trade Intensity	-0.004	0.002	-1.85	0.066	-0.008	0.000	*
Carbon Intensity	0.001	0.013	0.05	0.957	-0.025	0.027	
TI x TI	0.000	0.000	1.45	0.148	0.000	0.000	
CI x CI	0.000	0.000	0.25	0.801	0.000	0.000	
CI x TI	0.000	0.000	1.15	0.250	0.000	0.000	
Employment (ln)	0.002	0.029	0.06	0.952	-0.056	0.059	

**** p<0.01, ** p<0.05, * p<0.1*