# Master Thesis

## Does the European Emission Trading System Cause Carbon Leakage?

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# Does the European Emission Trading System cause Carbon Leakage?

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# Preface

Dear reader, in front of you lies my master's thesis. This thesis is the product of six months of hard work, in which I learned a lot of new things. Before this thesis, I had never performed a regression analysis, and I had no clue what "panel data" meant. After this thesis, I feel quite comfortable reading scientific articles on the topic of econometric policy analysis. That would not have been possible without the guidance of my first supervisor, Enno Schröder, who always had time to answer my questions and made the effort to follow up on discussions and even send me additional interesting links and tips. I would also like to thank my second supervisor, Hans de Bruijn, for providing feedback during the kick-off, mid-term and greenlight meetings and for triggering me to also view my research from a policy analysis perspective. Making it through the thesis would have been a lot harder without the support of my family, girlfriend, housemates and other friends, thank you for always being there for me, helping me when I got stuck, or making me realise that it is sometimes necessary to not try to make everything perfect. I am quite proud of the thesis I managed to produce in six months, so I thoroughly hope that you will enjoy reading this piece and that the findings and recommendations will give you some food for thought regarding the European Emission Trading System and the competitiveness of European Industry.

Jurriën Kuin

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# Executive Summary

The European Union Emissions Trading System (EU ETS), implemented in 2005, is the first and largest environmental policy to put an explicit price on carbon emissions. By setting a cap on total emissions and allowing the trading of emission allowances, the EU ETS incentivises companies to reduce their carbon footprint. However, this policy has raised concerns about its impact on the competitiveness of European firms and the potential for carbon leakage. Carbon leakage occurs when firms, due to the EU ETS, relocate or lose market share to regions with less stringent environmental policies. In the first ten years of the EU ETS, there was a surplus of allowances, prices were low, and no evidence of carbon leakage was found. However, since 2018, the price of allowances has increased significantly, and free allocation of allowances has decreased, which warrants new concerns about carbon leakage. If it occurs, carbon leakage would hurt the European economy, cause people to lose jobs and make the EU more dependent on other economies. Whether carbon leakage has occurred will have consequences for how the EU can adapt the rules of the EU ETS and for any other country currently designing a similar ETS. Furthermore, research on the link between the EU ETS and carbon leakage will also contribute to the broader academic literature on the competitiveness effects of environmental policies. Therefore, this thesis investigates whether the EU EUTS has caused carbon leakage in recent years. Specifically, it aims to answer the research question: "Does the European Union Emissions Trading System cause carbon leakage?" Furthermore, the study also seeks to further the understanding of sectors at risk of carbon leakage by finding out whether carbon leakage, if it happened, occurred more for some sectors than for others.

A literature review was performed to find out what empirical evidence of carbon leakage exists, what factors influence the carbon leakage risk of sectors, how the EU ETS design influences carbon leakage risk and how the environmental policy stringency of the EU ETS can be measured. The literature review highlights that while early studies (using data up to 2014) found no evidence of carbon leakage due to the EU ETS, studies using data from after 2015 have found some signs of carbon leakage. However, these studies leave a gap in the literature since they do not take into account the allowance price explicitly, they do not distinguish between different sectors, and since their date of publication, more recent data has become available. The literature review further shows that two main sectoral characteristics influence carbon leakage risk, which will be taken into account in the analysis: emission intensity and trade intensity. The European Commission has tried to prevent carbon leakage due to the EU ETS by giving away emission allowances for free. This "free allocation" reduces the risk for sectors by reducing their costs due to the EU ETS. Based on sharp thresholds in terms of emission and trade intensity, the European Commission determines an official list of sectors "at risk of carbon leakage". Sectors on this list receive more free allocation than the

other sectors. This sharp division between sectors raises concerns about the risk of carbon leakage for sectors that fall just outside the carbon leakage list. Finally, a review of existing measures of environmental policy stringency used in empirical research shows that a measure based on EU ETS costs used by some authors has a high potential to bias the results against finding carbon leakage.

This study uses trade flow data to empirically assess the impact of the EU ETS on carbon leakage. If carbon leakage occurs, imports to the EU should increase, and exports from the EU should decrease. This happens because the quantity of production in the EU is reduced while it increases elsewhere. A novel measure of environmental policy stringency is used to minimise the potential for bias that comes with using a measure based on EU ETS costs. The novel measure defines environmental policy stringency as the EU allowance price, as the allowance price is deemed to be an accurate reflection of the impact the EU ETS has on firms. This measure is the same for all sectors and does not take into account any sectoral risk factors. Therefore, to study the impact of differences in sectoral carbon leakage risk, two groups of sectors with high carbon leakage risk are identified. First, sectors on the official carbon leakage list are sectors with high emission and trade intensity, which, therefore, have a high risk of carbon leakage. However, these sectors also get the highest percentage of free allocation. Thus, a second group of high-risk sectors is identified: those just below the carbon leakage list threshold. These sectors have moderate emission and trade intensity, but they receive less free allocation. The trade flow data is analysed using Ordinary Least Squares regression, with the novel measure of environmental policy stringency as the independent variable and trade flow as the dependent variable.

Because of methodological improvement in one area, a new shortcoming was created, which limits the ability to answer the main research question. Due to the use of the novel environmental policy stringency, which is non-sector-specific, it is difficult to control for the general deindustrialisation trend in the EU. Therefore, in solving one issue, a new one was created, and this study does not allow a definitive causal relationship between the EU ETS and carbon leakage to be established based on its results. However, the results still provide some interesting findings.

The results indicate that there is a highly significant and economically relevant correlation between the rising allowance price and an increase in imports to and a decrease in exports from the EU. An increase in the EU allowance price of 100 euros is associated with an increase in imports and a decline in exports of around 18%. Furthermore, the results differ depending on the group of sectors under examination. For sectors on the official carbon leakage list, the association between the allowance price and trade flows is significantly larger than for other sectors. For these sectors, an increase in the allowance price of 100 euros is associated with an increase in imports and a decrease in exports of around 26%. Interestingly, for sectors just below the carbon leakage list threshold, the correlation between the allowance price and trade flows is smaller, even compared to sectors with even lower emission- and trade intensity. All of these results are very robust in terms of the number of countries included in the dataset. Further robustness tests show that the findings are more sensitive to removing years 2020-2022 from the dataset, with some of the estimates becoming insignificant. These findings make sense, given that most of the movement in the allowance price happened from 2020-2022.

Due to the chosen methodology, claiming a definitive causal relationship between the EU ETS and carbon leakage is not feasible due to the potential for bias. Therefore, more research is needed to firmly establish that the EU ETS caused carbon leakage, as recent studies indicate but have not thoroughly proven. This study highlights the challenges in choosing a methodology that is free of bias and allows for the identification of a causal effect of the EU ETS on trade flows. Therefore, future empirical carbon leakage research should focus on reducing these sources of bias, possibly through the use of the instrumental variables method, as done by some earlier studies.

For European policymakers, the results from this study highlight some important facts. First of all, there are clear signs that the EU is losing competitiveness because imports rise and exports fall in manufacturing and mining & quarrying sectors. This issue is also reflected in public discourse, with news agencies reporting about the "deindustrialization of Europe. These competitiveness effects provide a clear challenge to European policymakers given the fact that the EU finds itself in a situation with increasing geopolitical tensions, where the strategic autonomy of the EU is at the forefront of policymakers' minds. From this study, it is unclear what factors cause the changes in trade flows. Therefore, the European Commission (EC) should first aim to find out what caused the competitiveness effects and how large the contribution of the EU ETS is. Afterwards, the EC can adapt the EU ETS based on these findings. Finally, the EC needs to develop a vision of what it wants the European industry to look like in the future. The EC needs to meet ambitious climate goals, while at the same time keeping the EU autonomous and competitive in a challenging geopolitical context.

To conclude, while the results from this study do not definitively attribute carbon leakage to the EU ETS, this study does demonstrate the challenge of choosing a method that is free of bias and thereby provides valuable methodological insight. Other researchers and policymakers are encouraged to use these findings to guide future research on the impact of the EU ETS on carbon leakage. They can then use their findings to inform the evolution of the EU ETS, ensuring it remains a robust tool in the fight against climate change without unduly compromising firm competitiveness.

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# Chapter 1

# Introduction

Climate change is one of the largest global problems of this age. This phenomenon is caused by the continuous emission of large amounts of greenhouse gases, predominantly $CO_2$ (IPCC, 2021). Therefore, in the last decades, policymakers have tried to reduce $CO_2$ emissions by creating environmental policies. These environmental policies impose regulations on $CO_2$ emitters in their jurisdiction to reduce their emissions. However, when these emitters are firms that face high competitive pressure, there are concerns that environmental policies harm the competitiveness of these firms and cause them to lose market share or even relocate outside the jurisdiction to a place without environmental policies. If these concerns are true, the emissions of these firms "leak" from regulated to unregulated jurisdictions. The term "carbon leakage" describes these competitiveness effects that occur if a firm, for reasons of costs related to environmental policy, leaves a country or loses market share to a country with less stringent environmental regulation (Branger & Quirion, 2014).[1] The competitiveness effects and associated carbon leakage are undesirable because they hurt the economy, cause people to lose jobs and make the jurisdiction more dependent on other economies.

When discussing the impact of environmental policies on carbon leakage, there is no getting around the European Union's Emission Trading System (EU ETS). Implemented in 2005, the EU ETS is the first and largest environmental policy to put an explicit price on carbon emissions (European Commission, 2024d). The EU ETS is a *cap-and-trade* system, meaning the system *caps* the total amount of greenhouse gas emissions by supplying a limited amount of emission allowances each year. These "EU allowances" can then be *traded* in the carbon market. EU allowances are certificates that give firms the right to emit greenhouse gases; one EU allowance gives a firm the right to emit one tonne of $CO_2$ equivalent greenhouse gases. At the end of each year, firms covered by the EU ETS must surrender enough allowances to cover their emissions of that year. The EU ETS covers over 10.000 plants in the energy, mining

[1] In a different strand of literature, the term carbon leakage is used in a broader sense to describe all ways in which environmental policy by one country can cause emissions to increase or decrease in other countries. This literature strand does not only consider foreign emission increases due to competitiveness effects, but also through other channels. Through the energy market channel, for example, a decreased demand for fossil fuels in the regulated region is supposed to suppress global prices, which raises the demand for fossil fuels outside the regulated region and thereby negates part of the emission reductions and causing carbon leakage. However, in this research I will not consider these other channels of carbon leakage and stick to the narrower and more common definition of carbon leakage as *only* relating to the competitiveness effects of firms leaving or losing market share and *thereby* increasing emissions elsewhere. This is also how the EU uses the term in its communication surrounding the EU ETS.

& quarrying, manufacturing and, more recently, aviation, and shipping sectors in all EU member states as well as Liechtenstein, Norway and Iceland. In 2022, the EU ETS generated a total revenue of USD 42 billion, which is 43.4% of all worldwide carbon pricing initiative revenue (World bank, 2023). The European Commission (EC) distributes the revenues of the EU ETS to its member states to support investments in renewable energy, energy efficiency improvements and low-carbon technologies (European Commission, 2024f).

Ever since the start of the EU ETS in 2005, there have been concerns about the system harming the competitiveness of European firms and thereby causing carbon leakage (European Commission, 2024b). However, research on carbon leakage for the *early years of the EU ETS*, until around 2014, of the EU ETS has shown no evidence of carbon leakage occurring (Branger et al., 2016; Dechezleprêtre et al., 2022; Naegele & Zaklan, 2019). However, that does not mean carbon leakage concerns regarding *later years of the EU ETS* are completely unfounded either. The reason for the lack of carbon leakage in the EU ETS's early years is not certain. However, researchers mention two main possible reasons: A low allowance price (Dechezleprêtre et al., 2011; Naegele & Zaklan, 2019) and a surplus of allowances (Branger et al., 2016; Dechezleprêtre et al., 2022). At the start of the EU ETS, in phases 1 (2005-2007) and 2 (2008-2012), allowances were given to firms based on their historical emissions. This method of giving away allowances is known as "free allocation" (European Commission, 2024a). Because of the economic crisis of 2008, firms decreased their production and did not need all the allowances they received, which caused a large surplus of allowances. The large over-supply of allowances, in turn, is mentioned as one of the reasons the allowance price was relatively low throughout the early years of the EU ETS (European Commission, 2024d).

Since 2013, at the start of phase three (2013-2020), the EC has switched the main method of distribution of allowances from free allocation to auctioning. This means most firms now have to buy some of their allowances through auctions instead of receiving them for free. However, the EC still supplies a large part of the allowances through free allocation to reduce the risk of carbon leakage. The percentage of allowances firms receive through free allocation decreases over the years, such that firms have to buy an increasing part of their allowances through auction. All the way until the end of 2017, the EU allowance price remained below 10 euros, before it started to increase again following political agreement on reforms for phase four of the EU ETS (2020-2030)(Verde, 2020). From 2018 to 2022, the allowance price increased tenfold to almost 100 euros, see Figure 1.1. The large price increase combined with lower levels of free allocation means that the costs of the EU ETS for firms have also increased a lot. Therefore, one might wonder if the concerns of the EU have finally become true and carbon leakage has started to occur in recent years. There is no immediate and clear answer from the literature, but there are some early signs of evidence of carbon leakage (De Beule et al., 2022b; Wang & Kuusi, 2024). A literature review will show what evidence of carbon leakage has been found and where gaps in the knowledge lie, all of which will be discussed in chapter 2. This chapter will also show that measuring carbon leakage due to an environmental policy, like the EU ETS, is a non-trivial issue. It will explain different methods of measuring the EU ETS's impact on firms, or in other words, what the "environmental policy stringency" of the EU ETS is. Finally, the chapter will explain the pitfalls of existing measures of environmental policy stringency and present a novel measure based on the EU allowance price.

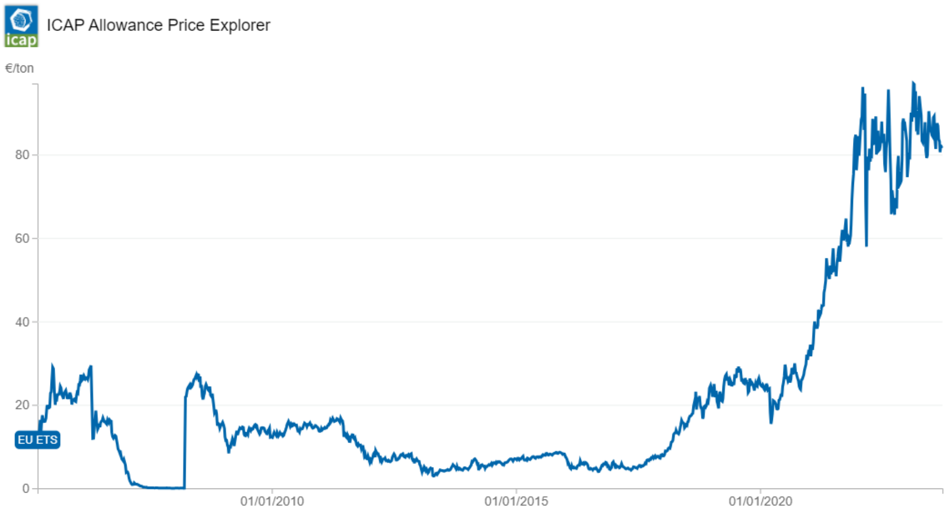



**Figure 1.1**
EU allowance price history, in EUR/t$CO_2$. From *ICAP allowance price explorer* by International Carbon Action Partnership. Retrieved January 19, 2024, from https://icapcarbonaction.com/en/ets-prices

Why should we care whether carbon leakage has started to occur in recent years? First of all, if carbon leakage occurs, European firms either lose market share or move their production abroad. As explained earlier, this could hurt the EU's economy, cause people to lose jobs, and make the EU more dependent on other economies. Therefore, if the EC considers the scale of carbon leakage unacceptable, it might need to increase free allocation to firms to protect them even more against carbon leakage or find a different protection mechanism. However, protecting firms against carbon leakage does come at a cost. Free allocation is costly because it reduces the EU ETS's revenues, which then cannot go towards investment in emission reduction. If no carbon leakage occurs, even though the price increased and free allocation was reduced, it means that the EC can safely reduce free allocation further. Thereby increasing revenues, which member states can use to invest in emission-saving innovation. These issues are also of interest to any other country wanting to implement an emission trading system. The learnings from the first and largest system, the EU ETS, will help other countries develop their ETSs more effectively with a lower chance of carbon leakage and, at the same time, more revenues and more emission-saving innovation. Finally, research on carbon leakage in the EU ETS will also contribute to the wider academic literature on the impact of environmental policies on competitiveness and carbon leakage. The EU ETS is the ideal case to study the impacts of environmental policy on carbon leakage because it is the ETS with the highest price and the largest coverage rate in terms of total emissions. Furthermore, there is a large availability of high-quality data.

When discussing carbon leakage, a key factor is always the sectors under examination. Some sectors have a much higher risk of carbon leakage. They are more emission-intensive, or face more competition from outside the EU. That is why certain sectors officially classified by the EC as "at risk of carbon leakage" receive more allowances for free (European Commission, 2024b) and why some carbon leakage studies focus only on high-risk sectors such as cement and steel (Branger et al., 2016). Knowing in what sectors carbon leakage occurs, the EC can target additional free allocation towards these sectors. Similarly, knowing what sectors do not experience carbon leakage, the EC can reduce any unnecessary free allocation to these sectors. To be able to develop hypotheses about which sectors experienced carbon leakage, two things need to be known. First, one needs to know what factors influence the risk of carbon leakage. Secondly, one needs to know how the EC has designed the free allocation rules of the EU ETS, which differ per sector, to reduce the risk of carbon leakage. These issues will be covered in section 2.3 and section 2.4 respectively.

So, to summarize, the European Union Emission Trading System (EU ETS) is the largest environmental policy in the world. Ever since the start of the EU ETS there have been concerns that the system has decreased the competitiveness of firms in the EU and caused "carbon leakage". In the first 10 years of the EU ETS, there was a surplus of allowances, prices were low, and no evidence of carbon leakage was found. However, since 2018, the price of allowances has increased a lot, and free allocation has decreased, which warrants new concerns about carbon leakage. Whether carbon leakage has indeed started occurring will have consequences for how the European Commission can adapt the rules of the EU ETS and for any other country currently in the process of designing a similar ETS. Furthermore, research on the link between the EU ETS and carbon leakage will also contribute to the wider academic literature on the competitiveness effects of environmental policies. Finally, finding out whether carbon leakage occurred more for some sectors than for others will further the understanding of sectors at risk of carbon leakage and help the EC target its policies. For these reasons, this study aims to determine whether carbon leakage has occurred in the EU ETS in recent years by answering the following research question

**Does the European Union emission trading system cause carbon leakage?**

and the following sub-questions:

1. What do the theory and empirical evidence from the literature tell us about carbon leakage due to the EU ETS?
2. What sectoral characteristics influence carbon leakage risk?
3. How has the European Commission designed the EU ETS's free allocation rules to prevent carbon leakage?
4. What measures of environmental policy stringency exist, and what measure can best be used to study the impact of the EU ETS on carbon leakage in recent years?
5. Is there statistically significant and practically relevant evidence that the EU ETS caused carbon leakage?
6. How do sectoral carbon leakage risk factors and the free allocation rules of the EU ETS influence the results?

# Chapter 2

# Literature Review and Background

The goal of this study is to find out whether the European Union's emission trading system has caused carbon leakage. This chapter will review the literature and find out whether empirical research has found evidence of carbon leakage due to the EU ETS in recent years. The review will show that there are some early signs of leakage occurring through foreign direct investment, but that more research is needed to be able to draw conclusions about how large the carbon leakage issue is. However, to be able to understand the empirical evidence and its implications it is important first to understand how an environmental policy can cause competitiveness effects and thus carbon leakage. Therefore, section 2.1 will first describe the literature on the link between environmental policies, competitiveness effects and carbon leakage. This section will also explain how carbon leakage can be measured by analysing trade flows. Trade flows are simply the imports and export flows between countries. After this more general part of the literature review, section 2.2 will describe the empirical evidence of carbon leakage. This will allow the identification of a research gap this study aims to fill, which will be described in subsection 2.2.4. Then it is time to address one of the other main issues identified in the introduction, how sectors differ in terms of their carbon leakage risk, in section 2.3. Based on these carbon leakage risk factors, the European Commission (EC) determines whether a sector is officially classified as "at risk of carbon leakage" and put on the "carbon leakage list". If a sector gets this classification it receives more free allocation than sectors not on the list. Section 2.4 will describe how the EC determines the carbon leakage list and how the free allocation a sector receives is dependent on this list. The sectoral carbon leakage risk factors, together with the EU ETS's free allocation rules, provide the basis for how the stringency of the EU ETS can be measured and used in the empirical analysis. Section 2.5 will describe how other studies have measured environmental policy stringency and why this study will use a novel measure of environmental stringency based on the allowance price. Finally, section 2.6 will describe the two main economic theories of international trade, how these theories can be used to model trade flows empirically and why I will use bilateral trade flows in this study.

## 2.1 Environmental Policies, Competitiveness Effects and Carbon Leakage

From the introduction in chapter 1, we know that environmental policies lead to concerns about the competitiveness of firms regulated by the policy and about carbon leakage. This has been the case ever since the first major environmental regulations were enacted in the US in the 1970s (Jaffe et al., 1995). However, the introduction did not explain in full detail how an environmental policy causes these concerns, which is what this section will do. This section will use a major review on the topic of environmental policies and competitiveness, by Dechezleprêtre and Sato (2017) to describe what the desirable and undesirable effects of environmental policies are and how these relate to two main hypotheses: The pollution haven hypothesis and the Porter hypothesis.

Environmental policies affect firms' competitiveness in multiple ways. These effects all result from the costs imposed by the policy on firms and firms' reactions to these costs. The EU ETS imposes costs on firms by requiring them to buy and surrender allowances to cover their emissions, so-called "direct costs". Furthermore, the EU ETS increases electricity prices because electricity generators also have to buy emission allowances. The resulting higher costs for firms that have to buy electricity for their processes are called "indirect costs". The higher relative production costs due to the EU ETS lead to a variety of effects. Dechezleprêtre and Sato (2017) divide the competitiveness effects of differences in environmental policy stringency into three orders, see Table 2.1. The first-order effect is the direct impact: The increase in the relative cost of firms due to the policy. Then, the second-order effects are the responses of firms. Finally, third-order effects are the economic, technology, international, and environmental outcomes. Dechezleprêtre and Sato note that *"These effects are not uni-directional, rather there are multiple linkages and dynamic feedbacks. Changes to technology outcomes, for example, may trigger cost impacts or firm responses to change."* (Dechezleprêtre & Sato, 2017, p.186). So, there are many different effects of any environmental policy, which are all linked to each other. However, the goal of this study is to measure the effect of the EU ETS on one particular outcome: whether carbon leakage occurred. Carbon leakage is shown in the table as "pollution leakage". The fact that it is mentioned in the table does not mean that carbon leakage can be directly measured. Directly measuring carbon leakage would entail something like tracking market share losses and relocation decisions of all firms covered by the EU ETS and then, in some way, trying to determine whether these effects were actually due to the EU ETS. Clearly, this approach is not feasible, not in the least because of the huge requirements in terms of time and data. Therefore, economists have come up with other ways of measuring carbon leakage.

We will now discuss three ways of measuring carbon leakage. First, when talking about carbon leakage, the main concerns are that firms lose market share to outside EU competitors or, even worse, that firms relocate their production activities outside the EU. These two effects are both related to **international trade**. When European firms lose market share, but demand in and outside of the EU for these firms' products stays the same, imports of these products will rise, and exports of these products fall. The same happens when a firm relocates its production outside the EU; imports will rise, and exports will fall. That is why economists who study carbon leakage often study the impact of an environmental policy on trade flows. They use regression analysis to find out whether higher environmental policy stringency leads to higher imports and lower exports. Using regression analysis, it is possible to isolate the effect of the environmental policy and control for other factors that might otherwise explain trade flows. Another added benefit of studying carbon leakage through trade flows is that trade flow data, on the sector level, is available for almost all countries and for a large range of years. A second possible method of measuring carbon leakage uses firm-level data on **Foreign Direct Investment (FDI)** of multinational enterprises (MNEs) (De Beule et al., 2022b; Dechezleprêtre et al., 2022; Koch & Basse Mama, 2019). FDI by European firms outside the EU can signal the relocation of these firms' production facilities to other countries. An issue with FDI data is that it only indicates something about the relocation of firms outside the EU and nothing about the loss of market share of European firms. Furthermore, FDI data of MNEs is much less readily available than trade data and often requires access to proprietary datasets De Beule et al. (2022b) and Koch and Basse Mama (2019). Finally, as a third method, one might wonder whether it is possible to **qualitatively study** whether the EU ETS caused carbon leakage, for example, through interviews or surveys of firms. Although this method is used to identify carbon leakage risk factors (Martin et al., 2014), its use to quantify the effect of the EU ETS on carbon leakage would require a lot of resources. Therefore, I will study carbon leakage by performing a regression analysis on trade flows, following the example of some of the main empirical works on this topic (Aichele & Felbermayr, 2015; Branger et al., 2016; Naegele & Zaklan, 2019).

| First-order effect | Second-order effect | Third-order effects | | | |
|---|---|---|---|---|---|
| Cost impacts | Firm responses | Economic outcomes | Technology outcomes | International outcomes | Environmental outcomes |
| Changes to relative costs (direct and indirect costs) | - Production volume<br>- Product prices<br>- Productive investments<br>- Investment in abatement | - Profitability<br>- Employment<br>- Market share | - Product innovation<br>- Process innovation<br>- Input-saving technologies<br>- Total factor productivity (TFP) | - Trade flows<br>- Investment location<br>- Foreign direct investment (FDI) | - Pollution levels and intensity<br>- Pollution leakage |

**Table 2.1**
Competitiveness Effects Due to Differences in the Stringency of Environmental Regulations. From *The Impacts of Environmental Regulations on Competitiveness*, by Antoine Dechezleprêtre and Misato Sato, 2017, *Review of Environmental Economics and Policy,*, volume 11, issue 2, p. 186 (doi: 10.1093/reep/rex013), CC-BY-4.0

Regarding the effects of environmental policies on the competitiveness of firms, there are two main hypotheses about the size and direction of these effects: The pollution haven hypothesis and the Porter hypothesis. First, the **pollution haven hypothesis** states that environmental policies in one country will cause firms from that country to relocate to a country with less stringent environmental policies. These countries with low environmental stringency will accumulate emission-intensive firms, thereby becoming so-called "pollution havens" (Copeland & Taylor, 1995; Levinson & Taylor, 2008). This idea is essentially the same as the idea of carbon leakage. Therefore, many studies on carbon leakage use the terminology pollution havens[1], and some studies examine whether carbon leakage is more likely to happen towards countries that can be classified as pollution havens (De Beule et al., 2022b) Second, in reaction to the generally prevalent negative view that environmental policies decrease the competitiveness of firms, renowned economist Michael Porter stipulated the "**Porter hypothesis**". The idea behind the Porter hypothesis is that environmental policies will force firms to innovate in more environmentally friendly and efficient technology, increasing their productivity, offsetting any negative effects and getting ahead of the competition (Porter & van der Linde, 1995). [2]

Evidence for these two hypotheses has been examined in the literature. Dechezleprêtre and Sato (2017) reviewed the empirical evidence regarding the pollution haven and Porter hypothesis. Regarding the Porter hypothesis, they found clear evidence that environmental policies induce innovation in cleaner technologies. Calel and Dechezleprêtre (2016), for example, find that the EU ETS increased innovation in low-carbon technologies with 30%. However, there is no evidence that these innovations completely offset negative effects and *increase* the competitiveness of firms. Because there is no evidence the Porter hypothesis is true, one might wonder whether the opposing pollution haven hypothesis does find support, which would also mean that carbon leakage does occur. Dechezleprêtre and Sato (2017), in their review, find no evidence that environmental policies have had *large* adverse effects on competitiveness. They do find some evidence in favour of the pollution haven hypothesis, but the scale of these effects is very small compared to other factors that influence competitiveness and the effects are concentrated in a small set of energy-intensive sectors for which costs due to the environmental policy are significant. Crucially, as a reason for the lack of adverse competitiveness effects, the authors note that the cost burden due to environmental policies has generally been found to be very small. This result aligns with the findings presented in the introduction regarding the absence of carbon leakage in the early years of the EU ETS, when prices were very low and free allocation was generous. The next section will dive deeper into the literature and describe the empirical evidence of carbon leakage.

## 2.2 Empirical Evidence of Carbon Leakage

The previous section explained that carbon leakage and pollution haven literature are closely related. The term "carbon leakage" has gained traction more recently when most of the pollution concerns became related to climate change and carbon emissions. When looking for evidence of carbon leakage, it is important also to consider evidence in favour of the pollution haven hypothesis. Therefore, this section will first describe one of the main papers written about the pollution haven effect, in subsection 2.2.1. This is also one of the few papers that actually finds evidence of a pollution haven effect, by addressing problems in previous methods (Levinson & Taylor, 2008). Then, we will turn our attention towards carbon leakage. First, subsection 2.2.2 will describe an article that studied carbon leakage due to the

[1]Historically, climate change and carbon emissions were not such a well-known issue. Therefore, the term *carbon* leakage has been used more recently, whereas earlier literature focused on other pollutants

[2]The Porter hypothesis described here is the "strong" version, which states that environmental policies can actually increase competitiveness of firms. There is also a "weak" version of the hypothesis which only stipulates that well-designed environmental policies can lead to innovation, but that does not mean that the innovation offsets the negative competitiveness effects.

Kyoto Protocol in a worldwide context (Aichele & Felbermayr, 2015). The article has been important in the literature on carbon leakage because it found some first evidence of carbon leakage due to a climate change related policy and because it used a novel method which has later been copied by many other authors. Apart from studies in a worldwide context, there is also empirical research on carbon leakage due to the EU ETS. In subsection 2.2.3, these studies will be reviewed, focussing on studies that use data from recent years, since it is already known that earlier studies did not reveal evidence of any carbon leakage. Finally, the section will end by describing the research gap in subsection 2.2.4.

### 2.2.1 Empirical Evidence From the Pollution Haven Literature

Much of the earlier research on the link between environmental policies and competitiveness focused on the pollution haven effect. Most of this research concentrated on the United States since it had stringent environmental policies and a lot of data available. Of these pollution haven studies, most did not find evidence of a pollution haven effect (Dechezleprêtre & Sato, 2017). These studies often measure the impact of pollution abatement cost and expenditures (PACE) on trade flows. Where PACE is their proxy for environmental policy stringency, based on the idea that sectors that spend the most on pollution abatement are the ones that experience the highest cost due to environmental policy. PACE is used a lot in research on the pollution haven effect in the United States because it is one of the only measures of environmental policy stringency available for all states and with high accuracy (Dechezleprêtre & Sato, 2017). Levinson and Taylor (2008) demonstrate that some of the lack of evidence for a pollution haven effect can be explained by three methodological flaws, which may bias the estimates. **Bias** of regression estimates refers to any error that occurs when the estimated coefficients deviate from the true value of the population. Levinson and Taylor (2008) find that, after accounting for these flaws, there is actually a considerable impact of PACE on trade flows. The method I will use in this study is also based on regressing the impact of a measure of environmental policy stringency on trade flows, which is why it is important to consider the methodological flaws identified by Levinson and Taylor (2008).

Levinson and Taylor (2008) identify three methodological flaws that can cause bias. First, they show that using a simple cross-sectional dataset may bias estimates of a pollution haven effect. A cross-sectional dataset is a dataset consisting of multiple data points, so trade flows from multiple countries to multiple other countries, but of only one time point (a single year, for example). Using such a cross-sectional dataset does not allow one to account for unobserved heterogeneity. **Unobserved heterogeneity** is the variation in the data which is not explained by the explanatory variable. In the case of carbon leakage research, the explanatory variable is a measure of environmental policy stringency. The variation in the data can be caused by many different things that are hard to measure, such as institutional quality or cultural differences. Unobserved heterogeneity is a very common issue in any regression analysis. The bias caused by unobserved heterogeneity can be accounted for by using a panel dataset, instead of a cross-sectional dataset, and using fixed-effects estimation. A **panel dataset** is almost the same as a cross-sectional dataset, so including multiple trade flows for multiple combinations of countries, except that it has data over multiple points in time. Using such a panel dataset allows the analyst to incorporate so-called "fixed effects". These **fixed effects** account for unobserved heterogeneity of datapoints and thereby remove potential bias caused by unobserved heterogeneity. For this reason, I will use a panel dataset with fixed effects. The exact fixed effects I use and how they control for unobserved heterogeneity will be explained in section 3.1. Second, Levinson and Taylor (2008) show that a second source of bias can originate from environmental policies in other countries. The idea is quite simple: if two countries have a similar level of environmental policy stringency, there is no reason for the environmental policy stringency of one of the countries to impact trade flows to or from the other country. The third cause for bias arises when the unit of analysis is an aggregate of smaller units of analysis. In this study, the unit of analysis is a sector, which is an aggregate of sub-sectors or individual firms. Levinson and Taylor (2008) show that this "aggregation bias" may bias the regression estimates because an individual firm shutting down will impact both the measure of environmental stringency: PACE and trade flows. Levinson and Taylor (2008) account for these last two sources of bias by using an instrumental variables approach. I will account for these issues in my measure of environmental policy stringency, which will be explained in full detail section 2.5.

### 2.2.2 Empirical Evidence from the Carbon Leakage Literature in a Worldwide Context

When knowledge about climate change became widespread, attention shifted from more general pollutants to greenhouse gases and "carbon leakage". One of the first worldwide agreements on climate change mitigation was the Kyoto protocol (United Nations Framework Convention on Climate Change, 1997). Signed in 1997, the protocol set legally binding targets for developed countries, requiring them to reduce their emissions after 2005, when the protocol went into force. Because the Kyoto Protocol only required developed countries to reduce their emissions, it raises concerns of carbon leakage. Aichele and Felbermayr (2015) empirically studied whether the Kyoto Protocol induced carbon leakage. They analysed the impact of countries' commitment to Kyoto on trade flows using a panel dataset with fixed effects. Interestingly, they did not estimate the impact of the Kyoto Protocol on trade flows in monetary value, as used by previous studies, but instead, they estimated the impact on the carbon content of imports, or "embodied carbon". Aichele and Felbermayr (2015) argue that trade flows in embodied carbon more accurately proxy carbon leakage. They explain that it is the carbon content of trade flows that should change when countries establish environmental policies, and not necessarily the value of trade flows. Using their novel method Aichele and Felbermayr (2015) find that the Kyoto Protocol increased imports in embodied carbon by 8% and that the carbon intensity of these imports increased with around 3%. Therefore, they conclude that the Kyoto Protocol has indeed induced carbon leakage. The method of using trade flows in embodied carbon was later also used by other authors in the context of the EU ETS, most notably by Naegele and Zaklan (2019). Using trade flows in embodied carbon for this thesis is not feasible because it requires the use of input-output analysis. The input-output data is only available up until 2020, and not 2022 and is generally only available for a high level of aggregation. Naegele and Zaklan (2019) emphasize the importance of not using trade flows in value when studying carbon leakage. They explain that price fluctuations may lead to changes in trade flow in value unrelated to the environmental policy under investigation. Therefore, in this study I use trade flows in quantity, i.e. the kilograms of product traded between countries. I use trade flows in quantity because there is a more direct relation between energy, and thus emissions, and physical quantity than there is between energy and the value of products. That is also why Naegele and Zaklan (2019) recommend using trade flows in quantity when using trade flows in embodied carbon is unfeasible.

### 2.2.3 Empirical Evidence of Carbon Leakage due to the EU ETS

We will now focus on the environmental policy of interest in this paper, the EU ETS. The previous sections have shown that evidence of carbon leakage can be found in some cases using the right methodology. However, as explained in section 2.1, evidence of these effects is scarce and often practically quite small, partly due to the low costs induced by environmental policies. The EU ETS recently experienced a large increase in price together with a decrease in free allocation, which increased costs to firms. Because of its size and because it was the first of its sort, there is a large body of empirical research on carbon leakage due to the EU ETS, which all support the same conclusion: The EU ETS did not cause carbon leakage. (Branger et al., 2016; Colmer et al., 2024; Dechezleprêtre et al., 2018, 2022; Koch & Basse Mama, 2019; Naegele & Zaklan, 2019; Verde, 2020). However, all of these papers share another commonality: they only studied the early years of the EU ETS. The articles by Branger and Quirion (2014), Colmer et al. (2024), Dechezleprêtre et al. (2018), and Naegele and Zaklan (2019) are some of the most well-known and most cited empirical articles on carbon leakage due to the EU ETS, which all use data of the first two phases of the EU ETS, up to and including 2012. Dechezleprêtre et al. (2022) and Koch and Basse Mama (2019) use slightly more recent data up to and including 2014 and 2013 respectively. Verde (2020) reviewed the econometric evidence regarding the impact of the EU ETS on competitiveness and carbon leakage. He reviewed 35 articles published up to and including 2019, with the most recent paper using data up to and including 2016. Verde, too, concludes that at the point of writing the article, there was no evidence that the EU ETS had widespread negative effects on competitiveness or that there was significant carbon leakage. So, even though some of the articles were published quite recently, they often use data much older than the publication date. Verde (2020) is aware of this issue, stating that "The release of new data, their acquisition by applied researchers sufficiently familiar with the EU ETS and interested in it – not a multitude – the elaboration of non-trivial econometric analyses and their publication, are all steps that take time" Verde (2020, p.335). Therefore, it is important to look at the most recent research regarding carbon leakage due to the EU ETS and see if these results indicate that carbon leakage has occurred.

While using data from the first two phases (2005-2012) of the EU ETS is very common, as shown in the previous paragraph, thorough empirical research using data from phase 3 (2013-2020) or phase 4 (2021 onwards) is scarce. To the best of my knowledge, there are only two studies that empirically study the effects of the EU ETS on carbon leakage with recent data (after the price increase in 2017) (De Beule et al., 2022b; Wang & Kuusi, 2024). These two studies present some signs of evidence of carbon leakage. However, their methodologies do not allow for the answer to the research question with full confidence. That is why more research is needed. I will continue by describing these two recent studies and why they leave a gap in the literature.

First, Wang and Kuusi (2024) analyse the impact of the EU ETS on trade flows. The authors analysed whether being part of the EU ETS for a sector influenced trade flows to and from the EU. They used a regression analysis similar to Naegele and Zaklan (2019) using panel data with fixed effects to control for unobserved factors. Naegele and Zaklan (2019) performed arguably the most important empirical work on carbon leakage due to the EU ETS. Using data up to 2012, they conclude that the EU ETS does not cause carbon leakage (Naegele & Zaklan, 2019). Wang and Kuusi (2024), on the other hand, use data up to 2018 instead of 2012. Interestingly, they find that the EU ETS has increased the carbon content of imports to the EU. They claim that this is evidence that some carbon leakage has occurred due to the EU ETS. However, upon closer examination the validity of their results is doubtful. Wang and Kuusi (2024) find that over the full period of their data, from 2000 to 2018, the carbon content of imports increased for EU ETS sectors. They then split the results over phases one, two and three of the EU ETS. By doing this, they find that the carbon content of imports increases for phases one and two, but not for phase three. Consequently, their results indicate that carbon leakage occurred during the *early phases* of the EU ETS and *not during phase three*. These findings are in disagreement with the findings from numerous earlier studies that all find that there was no carbon leakage during phases one and two of the EU ETS. Therefore, the results from (Wang & Kuusi, 2024) cannot be accepted without further validation. I will now compare the methodology from Wang and Kuusi (2024) to the one used by Naegele and Zaklan (2019) to explore why there may be differences in the results.

There are two main aspects regarding the methodology of Wang and Kuusi (2024) that differ from the methodology used by Naegele and Zaklan (2019). These differences can explain the different conclusions regarding carbon leakage during the early phases of the EU ETS. First, Wang and Kuusi (2024) use a simpler environmental policy stringency measure. The authors measure the environmental stringency of a country and sector with a dummy variable. This variable is equal to one if the importing country is part of the EU ETS and the sector is covered by the EU ETS and zero otherwise. Naegele and Zaklan (2019) use a measure based on the actual emissions of sectors and also correct these emissions with the amount of free allocation; they then multiply these free-allocation corrected emissions with the allowance price to obtain a measure of the costs to a sector. Section 2.5 will go into more detail about the different possible measures of environmental policy stringency. It will also explain why both of these measures have downsides and why a novel measure that falls somewhere in between might be more appropriate. The second difference between the two papers is in the way they treat sectors. Wang and Kuusi (2024) use data on 14 sectors, of which 5 are part of the EU ETS. They then estimate the difference in trade flows between the sectors that are covered by the EU ETS and sectors that are not covered by the EU ETS to find out what the effect of the EU ETS is on trade flows. Naegele and Zaklan (2019) only include sectors that are covered by the EU ETS in their analysis. They estimate whether differences in costs imposed by the EU ETS on these sectors impact trade flows. On top of that, Naegele and Zaklan (2019) also isolated sectors officially classified by the EU as "at risk of carbon leakage". They found no effect for these sectors, which is in line with their general result that the EU ETS did not cause carbon leakage. These differences in methodology between Naegele and Zaklan (2019) and Wang and Kuusi (2024) can be the reason that their conclusions are different. With the majority of other research finding no carbon leakage in the early years of the EU ETS, the results by Wang and Kuusi (2024) regarding carbon leakage in these years should be viewed with scepticism. Therefore, we will now turn our attention towards the other article that uses more recent data and does show evidence of carbon leakage.

De Beule et al. (2022b) study the impact of the EU ETS on carbon leakage using data of the entire duration of phase 3, from 2013 to 2020. They use a method based on foreign direct investment (FDI) data. Their data comes from European multinational enterprises (MNEs) that are covered by the EU ETS. They test whether carbon inefficiency and higher environmental policy stringency increase the chance of investment in a country they classified as a "pollution haven", i.e. a country with lax environmental regulation. They measure the environmental policy stringency of the EU as the difference between a firm's emissions and the free allocation the firm receives. Interestingly, De Beule et al. (2022b) divide the MNEs into two groups: one group with MNEs that belong to a sector officially classified by the European Commission as "at risk of carbon leakage", and the other group with MNEs that do not have this classification. They estimate the impact of carbon inefficiency and environmental policy stringency on these groups separately. They find that both higher carbon inefficiency and high emissions compared to free allocation significantly increase an MNE's chance of investing in a "pollution haven". Therefore, they provide evidence of a pollution haven effect and of carbon leakage. Interestingly, they find the effect *only* for sectors officially classified as "at risk of carbon leakage". Thereby, their result shows that effects can differ depending on the group of sectors under examination. The study by De Beule et al. (2022b) shows evidence of carbon leakage, but it is limited in its scope. It only includes data on FDI, which is related to the relocation of firms, but it says nothing about losses of market share by firms. Furthermore, the results cannot be used to draw conclusions about the total scale of carbon leakage in the EU ETS. They only show that carbon inefficiency and carbon cost increase the chance of investment in an environmentally lax country.

### 2.2.4 Research Gap

To conclude this section, I will describe the gap in the literature which this study aims to fill. There is plenty of research regarding carbon leakage during the first two phases of the EU ETS (2005-2012), but the same cannot be said about phase three (2013-2020) and phase four (2021 onwards). Research into the later phases of the EU ETS has a higher chance of finding carbon leakage because it was only then that the price increased and free allocation was considerably reduced. The literature search has yielded only two articles that study carbon leakage due to the EU ETS for phase three and none that use data from the first years of phase four. The study by Wang and Kuusi (2024) found evidence of carbon leakage, but only for phases one and two. Thereby it contrasts with many other studies that found no evidence of carbon leakage during these phases. It cannot be viewed as undisputable evidence of carbon leakage. The study by De Beule et al. (2022b) does show evidence of carbon leakage. However, it only used data on foreign direct investment and showed that the EU ETS can increase the probability of investment towards pollution havens. Thereby, it does not provide evidence on the total scale of carbon leakage due to the EU ETS.

This thesis will contribute to the literature and fill in existing gaps in three main ways. First, it will use data up until 2022, which is two years more recent than the most recent literature. It is in these last two years that the allowance price experienced its largest increase, which makes it more likely that carbon leakage occurred in these years. Second, this thesis will validate the results by De Beule et al. (2022b) and find out whether the carbon leakage they find is also evident when analysing trade flows. Thereby also checking the results of Wang and Kuusi (2024), who do not find carbon leakage in phase three. Third, and finally, the results by De Beule et al. (2022a) show the importance of distinguishing between firms based on their risk of carbon leakage. They find that sectors on the official carbon leakage list have a higher chance of carbon leakage. Therefore, this thesis will test whether the same effect can be seen when trying to find carbon leakage by analysing trade flows. Thereby again validating the results from De Beule et al. (2022b). This thesis will add to the findings by De Beule et al. (2022b) by identifying a second group of sectors with a high potential for carbon leakage. To this end, section 2.3 will describe the sectoral factors that influence carbon leakage risk and section 2.4 will describe how free allocation influences leakage risk.

## 2.3 Factors Influencing Sectoral Carbon Leakage Risk

The research by De Beule et al. (2022b) discussed in the previous section has shown the importance of distinguishing between groups of sectors when discussing carbon leakage, as some sectors have a higher risk of carbon leakage than others. The factors that determine how much a sector's competitiveness is impacted by an environmental policy, and thus how high the risk of carbon leakage is, are well described in the literature and used by policymakers. This section will describe the different factors that influence sectoral carbon leakage risk.

There are a lot of factors that may influence carbon leakage, but there are only three that may be used in this study. The carbon leakage discussed in this study occurs when firms experience competitiveness effects due to an environmental policy. More specifically, when firms lose market share or relocate to countries with less stringent environmental policies. The method chosen in this study is to measure these effects by analysing trade flows. In general, there is a vast number of economic factors that influence the international competitiveness of firms and, thus, trade flows, such as relative factor prices (labour, capital, energy, land), availability of raw materials, taxation differences, non-climate policy differences, trade tariffs, transport costs, exchange rates, political stability, and others (Sato & Burke, 2021). Although these factors play a role in firms losing market share or considering relocating to another country, they are not *sectoral characteristics*. As such, they cannot be used to divide sectors into different leakage risk groups. Similarly, firm-level factors such as company culture and values, leadership and management or contact with the local community all play a role, but they cannot immediately be generalised for an entire sector. When considering only sector-level characteristics that can be used in the analysis, the number of possible factors is no longer so large. The literature identifies three main factors determining carbon leakage risk at the sector level: emission intensity, trade intensity (Martin et al., 2014) and sector mobility [3](Ederington et al., 2005). The first two factors are also the ones used by the European Commission to determine their official list of sectors classified as "at risk of carbon leakage" (European Commission, 2024b). Sector mobility is generally used less in applied work, even though Ederington et al. (2005) finds that it can play a role in determining carbon leakage risk. The following paragraphs will describe the three sectoral leakage risk factors in the context of the EU ETS.

First, **emission intensity** is the most obvious carbon leakage risk factor (Martin et al., 2014). If a sector is emission-intensive, it needs to buy more emission allowances, which means it has higher costs due to the EU ETS. Alternatively, if a sector is not emission-intensive at

[3] Ederington et al. (2005) use the terminology "industry mobility", but I use sector mobility to better fit the terminology of the rest of this study.

all, there are no costs due to the EU ETS and, therefore, there is no risk of carbon leakage. Because emission intensity is a clear determinant of carbon leakage risk, it is also often used in empirical work as part of a measure of environmental policy stringency. (Branger et al., 2016; De Beule et al., 2022b; Naegele & Zaklan, 2019). The emission intensity discussed here includes both direct emissions and indirect emissions due to electricity use.

The second carbon leakage risk factor is **trade intensity** (Martin et al., 2014). Higher trade intensity does not determine whether sectors face higher costs due to the EU ETS. Rather, it determines whether sectors can *pass through* these costs to their consumers by increasing the prices of their products. The idea is that sectors facing a high degree of international trade competition cannot increase their prices because of price competition with international competitors. If firms in these sectors would increase their prices, they would immediately lose market share to international competitors that do not face EU ETS regulations. Trade intensity is not exactly the same as the degree of international trade competition. However, observing and quantifying the "degree of international trade competition" is difficult, which is why trade intensity is often used as a proxy. The idea is that sectors with high trade intensity are also more likely to face a higher degree of international trade competition.

Finally, **sector mobility** factors influence how costly it is for a firm to relocate to a different country and thus cause carbon leakage (Ederington et al., 2005). *Higher* sector mobility gives a *higher* risk of carbon leakage because it is *easier* for firms in the sector to relocate. Sector mobility is actually not one directly measurable variable; it consists of three factors that together influence mobility. These three factors are transport costs, fixed plant costs, and the extent of agglomeration economies (Ederington et al., 2005). Ederington et al. (2005) identify these sector mobility factors and test their effect on carbon leakage for US manufacturing industries. First, **transport costs** are supposed to reduce sector mobility because they increase the costs of a product if the firm moves further away from the location of consumption. In other words, if a sector has high transport costs, because of bulky and heavy goods for example, they will likely be located close to their consumers. Therefore, the costs associated with relocation will be higher because transport costs will increase more. Second, **fixed plant costs** are the costs directly associated with a production facility, or "plant". They determine how expensive it would be to build a new plant and thereby influence industry mobility. Third, the **extent of agglomeration economies** is also supposed to decrease sector mobility. Agglomeration economies are benefits that result from firms being geographically close to their supply chain or similar firms, which reduces costs. Therefore, relocating away from an agglomeration economy increases costs for the firm. Ederington et al. (2005) empirically analyse the effect of these three sector mobility factors on moderating the impact of environmental costs on trade flows. Secondly, Ederington et al. (2005) find a significant effect of their environmental stringency measure on imports from developing countries for pollution-intensive sectors with a high sector mobility. Their results indicate that sector mobility does influence whether carbon leakage occurs. However, the effect is small compared to other factors that influence the relocation of firms. Also, data on transport costs, fixed plant costs and agglomeration economies is difficult to obtain. Therefore, sector mobility will not be used in this study to determine sectors at risk of carbon leakage.

## 2.4 EU Emission Trading System Design to Prevent Carbon Leakage

The European Commission (EC) designed and implemented the EU ETS. From the beginning of the design of the EU ETS, they were well aware of the risks of carbon leakage. Therefore, using a method of free allocation of allowances, they structured the EU ETS to prevent leakage (European Parliament and the Council of the European Union, 2003). Free allocation reduces the risk of carbon leakage because it reduces firms' costs. Firms have to buy fewer allowances themselves to cover their emissions. The amount of free allocation differs per sector. Sectors "at risk of carbon leakage" receive more free allocation than other sectors. Therefore, it is important to understand how the free allocation rules of the EU ETS are structured. These rules will then be taken into account when dividing sectors into different groups based on their carbon leakage risk. First, subsection 2.4.1 will describe what sectors are covered by the EU ETS. Then, subsection 2.4.2 will describe how the European Commission determines the amounts of free allocation per sector. In these sections I will only describe the EU ETS coverage and free allocation rules of phases 3 and 4 (from 2013 onwards) since these are the years I will include in the analysis.

### 2.4.1 Sectoral Coverage of the EU ETS and Sectors to be Excluded From the Analysis

The EU ETS does not cover every single tonne of greenhouse gas emitted in the European Union. Instead, it only covers emissions from around 10,000 large industrial installations and, more recently, aircraft operators within the EU. Together, these account for around 40% of the EU's total emissions (European Commission, 2024f). From the beginning, the EU ETS has covered industrial installations in the electricity, heat generation, manufacturing and mining & quarrying sectors. In 2012, aviation was added before the addition of maritime transport in 2024 completes the full list of sectors covered today. However, some of these sectors do not face any carbon leakage risk, which is why they will be excluded from the scope of this study. First of all, the electricity and heat generation sectors are excluded because these are installations that often only produce for domestic consumption or, otherwise, for other European countries. So, although these facilities have high emission costs, their products are very rarely traded across European borders and they do not face international competition. Therefore, they can directly pass through increased costs to their consumers and they do not face a risk of carbon leakage. Similarly, the aviation sector can also easily pass higher costs through to consumers. Aircraft operators have to surrender emission allowances for any flights within the economic area. Therefore, any competitors flying the same routes will have to comply with the exact same rules and there is no such thing as "international trade competition" in this case. Finally, the maritime transport sector was only added in 2024 and does not fall in the time period of the analysis. For these reasons, I will only consider the **manufacturing and mining & quarrying sectors** in this study. These are also the sectors that the European Commission considers when it determines the official carbon leakage list. (European Commission, 2009, 2014a, 2019a). The next section will describe how the European Commission determines the carbon leakage list and the differences in free allocation between sectors on this list and sectors outside the list.

### 2.4.2 Free Allocation Rules in the EU ETS

The European Commission sets the framework of the EU ETS, including the rules for free allocation of allowances. The previous section has explained that only sectors belonging to the manufacturing and mining & quarrying industries are taken into account when the EC determines the list of sectors at risk of carbon leakage. These industries are divided into 245 sectors based on the Statistical Classification of Economic Activities in the European Community, commonly referred to as NACE. This NACE classification is the standard classification of economic activities used in the EU. To determine the official carbon leakage list, the European Commission carries out a "carbon leakage assessment". Over phases three (2012-2020) and four (2021 onwards), three of these carbon leakage assessments were carried out. These assessments determined the official carbon leakage list for the periods 2013-2014, 2015-2020 and 2021-2030. This section will describe the criteria used to determine the official carbon leakage list. Furthermore, it will also describe the percentages of free allocation firms receive, both when they are classified as "at risk of carbon leakage" and when they are not.

The EC determines the amount of free allocation to installations within a sector using a system of **benchmarking**. This benchmarking system will be explained using the case of sectors on the official carbon leakage list. Installations that are part of a sector on the official carbon leakage list receive up to 100% of their emissions in terms of allowances. *Up to 100%*, because not all installations in the sector receive all the allowances they need to cover their emissions. Per sector, the European Commission determines a **benchmark** in terms of emissions per kg of product. This benchmark is based on the 10% most emission-efficient installations in that sector. Installations then receive up to 100% *of that benchmark* in terms of allowances. For the 10% most efficient installations, that means they may receive more allowances than they actually need. However, the other 90% of installations receive less free allowances than they need. This means they still have to buy some allowances through auctions to cover the extra emissions, even though their sector is on the carbon leakage list. It is important to stress this fact. By far, not all installations part of a carbon leakage list sector also receive 100% of their allowances for free. For many sectors, the average emissions per kg of product are 40-50% higher than the benchmark (European Commission, 2021). Using this system of benchmarking, the EU ETS awards the most efficient installations and provides an incentive for firms to reduce their emissions. Sectors not on the official carbon leakage list also receive part of their allowances for free based on the benchmarking system. However, instead of 100% of the benchmark value, these sectors received less, linearly decreasing from 80% in 2013 to 30% in 2020, staying at that level until 2026, after which it will decrease to 0% in 2030.

| EU ETS phase | Years | Leakage list criteria | Nr. of sectors on leakage list | % industrial emissions covered by the leakage list | Free allocation if on leakage list | Free allocation if not on leakage list |
|---|---|---|---|---|---|---|
| 3 | 2013-2014 | carbon cost >30%<br>or trade intensity >30%<br>or carbon cost >5%<br>and trade intensity >10%<br>or qualitative criteria | 164 | 98% | 100% of benchmark | 80% (2013) -<br>73% (2014) |
| 3 | 2015-2020 | carbon cost >30%<br>or trade intensity >30%<br>or carbon cost >5%<br>and trade intensity >10%<br>or qualitative criteria | 175 | 98% | 100% of benchmark | 66% (2015) -<br>30% (2020) |
| 4 | 2021-2030 | emission intensity x<br>trade intensity >0.2<br>or qualitative criteria | 63 | 96% | 100% of benchmark | 30% (2021 - 2026) -<br>0% (2030) |

**Table 2.2**
Official carbon leakage list criteria used by the European Commission to determine sectors at risk of carbon leakage. Criteria, nr. of sectors, industrial emissions covered and free allocation amounts from European Commission (2024b). Free allocation if not on the leakage list from European Commission (2011, p.45) for phase 3 and from European Commission (2018a, p.55) for phase 4.

Table 2.2 shows the criteria used by the European Commission in the three assessments to determine the official carbon leakage lists. In each phase, first, a quantitative assessment was performed, determining the bulk of the sectors at risk of carbon leakage. After this quantitative assessment, sectors that fell outside of the risk group could appeal for a qualitative assessment, which led to the inclusion of a few more sectors. The criteria for the quantitative assessment differed per phase. In phase three, sectors could be included on the leakage list by either carbon cost or trade intensity alone or by a combination of the two criteria. **Carbon cost** (or emission cost) and **trade intensity** are defined as follows (European Commission, 2014b):

$$\text{Carbon cost} = \frac{(\text{Direct emissions} + \text{Indirect emissions}) * \text{CO}_2 \text{ price}}{\text{GVA}} \; [\%] \tag{2.1}$$

$$\text{Trade intensity} = \frac{\text{Imports} + \text{Exports}}{\text{Turnover} + \text{Imports}} \; [\%] \tag{2.2}$$

The relatively unstrict criteria for phase three caused a lot of sectors to be included on the carbon leakage list. As can be seen in Table 2.2, 175 sectors out of 245 manufacturing and, mining & quarrying sectors (NACE classification) were included on the leakage list for the most part of phase three. It turned out that many sectors were included based solely on the trade intensity criterion while their emission intensity was negligible (European Commission, 2024b). See Figure 2.1 for a figure of the carbon leakage criteria of phase three applied to the sectors [4]. However, as noted in section 2.3, if a firm is not emission-intensive, there are also no costs due to the EU ETS, and thus no risk of carbon leakage. Therefore, Martin et al. (2014)

[4]The sectors used in the figure are sectors in the ISIC3 classification instead of the NACE classification since the ISIC3 classification is the one used later on in the analysis

criticized the approach used by the European Commission. The authors conducted over 400 interviews with managers from European firms covered by the EU ETS. They used these interviews to obtain a measure of carbon leakage risk and tested whether the criteria used by the European Commission correlated with the measure from the interviews. They found that emission intensity strongly correlated with carbon leakage risk, but they did not find a similar result for trade intensity. Therefore, they recommended the European Commission to change their carbon leakage criteria and make it impossible to select sectors based solely on trade intensity. The European Commission listened to these criticisms and changed the criteria for phase four.

For phase four, sectors were selected using a single measure based on a combination of emission intensity and trade intensity, called the **Carbon Leakage (CL) indicator**. *Emission intensity* here is different from the carbon cost used in the assessment for phase three. In calculating carbon cost, a certain average allowance price had to be assumed for the coming period, which had proven to be quite difficult (European Commission, 2014b). Therefore, the emission intensity criterion for phase four is independent of the allowance price. Trade intensity is calculated in the same way as for the phase three assessment. Emission intensity and the CL indicator are defined as follows (European Commission, 2019b):

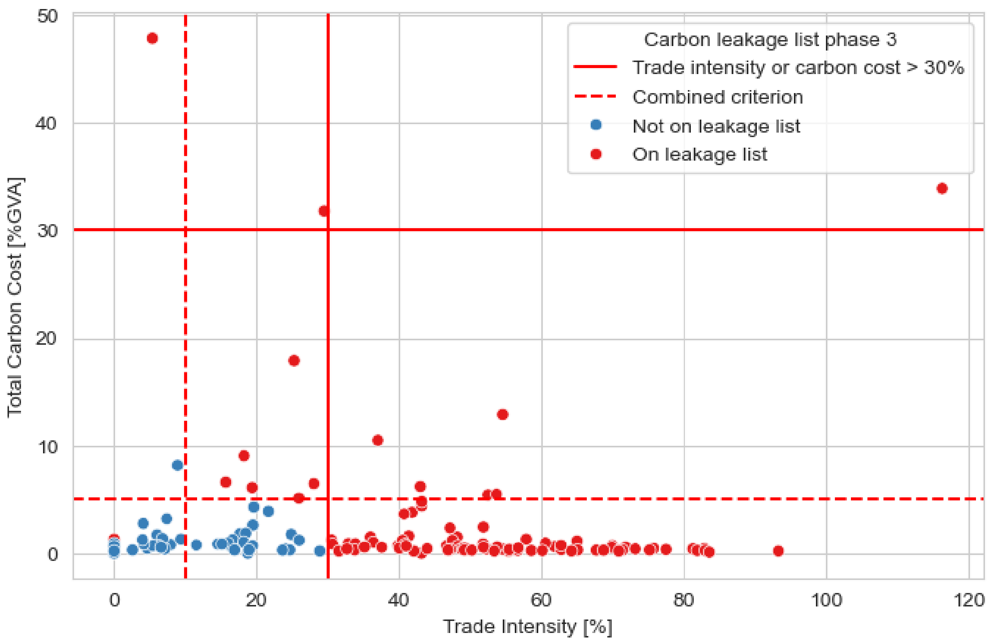



**Figure 2.1**
Official carbon leakage list criteria for phase 3 applied to the sectors. Sectors are mapped based on total carbon cost and trade intensity using data from the 2015-2020 detailed carbon leakage assessment results (European Commission, 2014c).

$$\text{Emission intensity} = \frac{\text{Direct emissions} + \text{Indirect emissions}}{\text{GVA}} \; [\text{kgCO}_2/\text{EUR}] \tag{2.3}$$

$$\text{CL indicator} = \text{Emission intensity} * \text{Trade intensity} \tag{2.4}$$

Using the new CL indicator, only 63 sectors were classified as at risk of carbon leakage. See Figure 2.2 for the criteria from phase 4 applied to the sectors covered by the EU ETS [5]. Although much fewer in number, these sectors still cover a similar percentage of industrial emissions compared to the phase three leakage list.

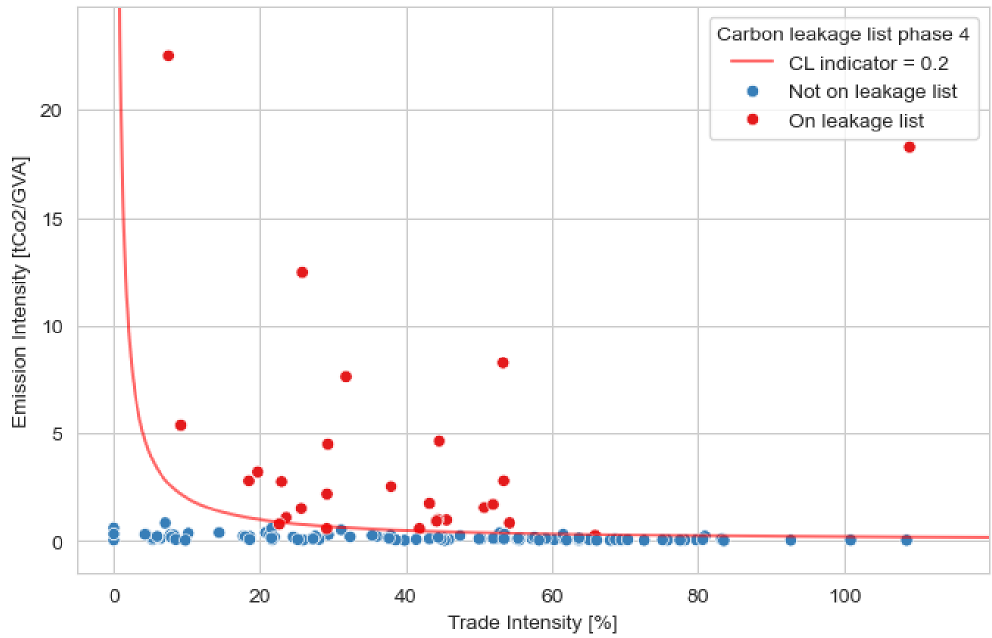



**Figure 2.2**
Official carbon leakage list criteria for phase 4 applied to the sectors. Sectors are mapped based on emission intensity and trade intensity using data from the 2021-2030 detailed carbon leakage assessment results (European Commission, 2018b).

The way the European Commission has structured the free allocation rules has a large impact on the actual carbon leakage risk these sectors face. It might be that the sectors officially "at risk of carbon leakage" are not actually the ones for which carbon leakage occurs. As we now know, these sectors receive quite a lot more free allocation than the other sectors, especially in recent years. Therefore, it might be the case that in recent years, sectors outside of the carbon leakage list actually had a higher risk of carbon leakage. On the other hand, as explained in section 2.2, the results from De Beule et al. (2022b) indicate that carbon leakage does occur for sectors on the official carbon leakage list. The information from this section regarding the free allocation rules, together with the sectoral carbon leakage risk factors from section 2.3, will be used in subsection 3.1.3 to divide sectors into groups of carbon leakage risk.

[5] The sectors used in the figure are sectors in the ISIC3 classification instead of the NACE classification since the ISIC3 classification is the one used later on in the analysis. Because of the conversion, some NACE sectors get combined into one ISIC3 sector, which is why there are less than 63 leakage list sectors in the figure.

## 2.5 How to Measure Environmental Stringency in the Case of the EU ETS

For any empirical study on the impact of environmental policies on carbon leakage, one of the most important methodological choices is how to measure "environmental policy stringency". To reiterate, environmental policy stringency is how much impact the environmental policy has on the entities it regulates. In the case of sector-level analysis of the EU ETS, environmental policy stringency should measure how much impact the EU ETS has on a sector. Environmental policy stringency is not a clearly defined metric that can be directly observed, which is why a proxy variable is used to measure environmental policy stringency. Section section 2.2 has already briefly mentioned some different options for the environmental policy stringency measure. This section will go into more detail to describe the different options and explain their benefits and downsides.

When discussing different options for environmental stringency measures there is one question that first needs to be answered: Do you measure environmental stringency only for the policy and countries of interest, or do you find a measure that can be applied to every country? Carbon leakage concerns stem from *differences* in environmental policy stringency. If two firms in different countries face the exact same regulations, there is no reason for these regulations to cause carbon leakage concerns. Therefore, in principle, an environmental policy stringency measure should have some level of environmental policy stringency for every country in the analysis. That is also why, if a study is not focused on a particular policy but rather on the general impact of environmental policies on carbon leakage, a measure is used that can be applied to any country. To this end, several environmental policy stringency indices have been developed. Of these, the OECD's EPS index is one the most often used (Brunel & Levinson, 2013). However, often studies are focused on a particular environmental policy, such as the EU ETS. In these cases, a measure that is more directly related to the policy of interest is mostly chosen. This allows the researcher to attribute the outcome effect to an element of the policy of interest. When a measure based only on the policy of interest is used, that essentially means one assumes the environmental policy stringency of all other policies to be equal to zero. This assumption is used by many empirical researchers (Aichele & Felbermayr, 2015; Branger et al., 2016; Colmer et al., 2024; Naegele & Zaklan, 2019). However, it is important to consider whether it is a valid assumption in this study as well. Originally, the EU ETS was one of the only environmental policies which put a price on carbon, but recently more carbon pricing initiatives have been implemented, resulting in a total of 73 instruments worldwide (World bank, 2023). Even though a lot more environmental policies have been implemented, the stringency of these policies is often very low. The EU ETS is still by far the most stringent environmental policy, with a carbon price almost twice as high as any other policy, see Figure 2.3, and generating 43.4% of all carbon pricing initiatives revenue (World bank, 2023). In an ideal world, one might want to correct for these other policies by obtaining a measure for each country. However, that would massively increase the requirements in terms of data and work in terms of data preparation. Therefore, I take only the environmental stringency due to the EU ETS into account, thereby assuming environmental policy stringency in other countries is zero.

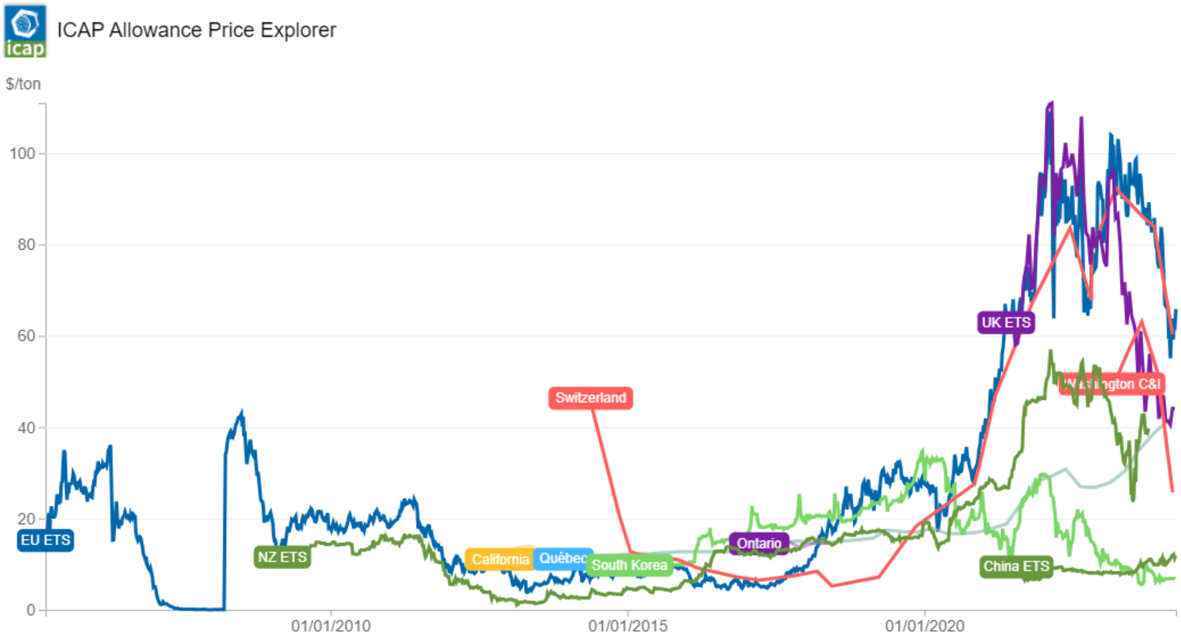



**Figure 2.3**
Allowance price for emission trading systems with the highest carbon prices. From *ICAP allowance price explorer* by International Carbon Action Partnership. Retrieved January 19, 2024, from https://icapcarbonaction.com/en/ets-prices

Even though the choice is made to consider only the environmental policy stringency of the EU ETS, there are still different ways to obtain such a measure. In general, there are two main categories of measures used: An EU ETS dummy or a measure based on EU ETS costs for a sector. Colmer et al. (2024) and Wang and Kuusi (2024) analyse the impact of the EU ETS on trade flows by using an EU ETS dummy variable. This treatment dummy indicates whether a sector and/or country is part of the EU ETS. Using such a dummy allows the researchers to compare whether being part of the EU ETS leads to higher imports and lower exports, as would be expected under the carbon leakage hypothesis. However, an EU ETS dummy does not allow the researcher to draw conclusions about *how* the stringency of the EU ETS impacts trade flows. In the EU ETS, the allowance price greatly impacts how much extra costs firms have to make due to the EU ETS. Similarly, the amount of free allocation also greatly impacts the costs for firms. Both of these issues are not taken into account explicitly when using a simple treatment dummy. Therefore, some researchers use a different measure based on EU ETS costs for a sector.

Naegele and Zaklan (2019) use an environmental stringency measure based on the costs the EU ETS imposes on sectors [6] When the goal is to measure how large the impact of the EU ETS is on trade for different sectors, a measure based on costs makes intuitive sense. A cap-and-trade system such as the EU ETS impacts sectors by increasing their costs. The costs

[6]There are other authors that also use a measure based on cost (Branger et al., 2016; De Beule et al., 2022b). However, I will use the method by Naegele and Zaklan to explain the concept since their measure is clear and intuitive to understand. However, the arguments I bring forward in this section about why I will not use the same cost measure also hold for other similar cost measures.

incurred by the system on sectors are a product of the emissions of these sectors, both direct and indirect, and the price of EU ETS allowances minus any free allocation. The measure of EU ETS costs as used by Naegele and Zaklan (2019) can be described as follows:

$$\text{EU ETS costs} = (\text{Direct Emissions} + \text{Indirect Emissions - Free allocation}) * P \tag{2.5}$$

Where EU ETS costs is a sector's cost due to the EU ETS in euros, the direct and indirect emissions of the sector are measured in $tCO_2$ (tonnes of $CO_2$ equivalent greenhouse gases), Free Allocation is the amount of allowances received by the sector in $tCO_2$, and $P$ is the price for an EU ETS allowance in euros/$tCO_2$. Because direct and indirect emissions and free allocation are all sector-specific and per year, the resulting EU ETS costs also becomes sector specific and per year. This is the specification of EU ETS cost that Naegele and Zaklan (2019) used for their environmental stringency variable. For their regression, they further normalized the EU ETS costs by sectoral material cost to obtain a measure independent of the sector's size, essentially converting it to sectoral **EU ETS cost *intensity***. At first glance, this seems like the perfect measure of environmental stringency for the EU ETS because it directly captures the costs the EU ETS imposes on sectors and even corrects for any free allocation of allowances. Furthermore, if the allowance price increases, the EU ETS costs to the sector increases, which is the impact I would like to capture for recent years. If the carbon leakage hypothesis is true, these higher costs will cause carbon leakage within this sector, which should be visible in the trade data.

However, this specification has an issue. Sectors comprise a heterogeneous mix of individual firms. Section 2.2 has explained that Levinson and Taylor (2008) identified three common issues that might arise when regressing environmental policy stringency on trade flows. One of these issues was "aggregation bias", which occurs if the unit of analysis (a sector, in this case) is a heterogeneous mix of smaller entities (firms, in this case). The aggregation bias, if not taken into account, may bias the results from the regression *against* finding carbon leakage (Levinson & Taylor, 2008). To understand how this works, let us go through an example using the EU ETS cost intensity measure. The EU ETS cost intensity of a *sector* is the *average EU ETS cost intensity* of the *firms* in the sector. If the sector is a heterogeneous mix of firms, it might very well be that the EU ETS cost intensity of some firms in the sector is quite different from the sector's average EU ETS cost intensity. Now imagine that carbon leakage occurs, which means a firm, due to the EU ETS, loses market share or decides to relocate outside the EU. This decreases the emissions of that firm in the EU. Therefore, because the sector is a heterogeneous mix of firms, the decrease in the firm's production will change the average EU ETS cost intensity of the entire sector. The further away the EU ETS cost intensity of the firm is compared to the sector's average, and the larger the firm is relative to the rest of the sector, the larger the change in the average EU ETS cost intensity of the sector will be. To better illustrate what the impact can be let us consider the case of a large firm which is much more emission-intensive than the average of its sector. If that firm has problems due to the EU ETS and decides to relocate outside the EU, the average EU ETS cost intensity will decrease by a considerable amount. Now, consider what this means for the regression analysis by looking at two time points. At timepoint one, the firm is still part of the EU and the EU ETS, at timepoint two, the firm has left the EU. From timepoint one to timepoint two, the average EU ETS cost intensity of the sector decreases because the large emission-intensive firm has left. That means that from timepoint one to timepoint two, the measure for environmental policy stringency has decreased. At the same time there is an effect on trade flows. Because of the firm leaving, imports have risen, and exports have gone down. Therefore, over these two time points, and this is the crux, *lower environmental stringency is correlated with higher imports and lower exports.* This effect is the *exact opposite* of what we would expect to see if carbon leakage occurs. In short, the very occurrence of carbon leakage, due to an emission-intensive firm relocating, causes the measure of environmental policy stringency to go down because it decreases the average EU ETS cost intensity of the sector. Therefore, lower environmental policy stringency becomes correlated with higher imports and lower exports, while it should be opposite if carbon leakage occurs. Therefore, specifying environmental stringency in this way may bias the estimate against finding a carbon leakage effect (Levinson & Taylor, 2008). This bias results from the sector being an *aggregate* of individual firms, hence the term "aggregation bias". It is not immediately possible to know how large this aggregation bias is. However, as explained in section 2.4, differences in emission intensity of firms compared to the most efficient firms in their sector can easily be 40-50% (European Commission, 2021). Therefore, differences in EU ETS cost intensity resulting from firms relocating can potentially be quite large. Therefore, for this study, I have chosen to use a novel measure of environmental stringency, which is not prone to aggregation bias. subsection 3.1.1 will describe what measure of environmental stringency that is.

## 2.6 Measuring Carbon Leakage Through Trade Flows, Empirical Trade Flow Theory

Section 2.1 has explained that this study will analyse the effect of the EU ETS on trade flows. However, there are different ways trade flows can be modelled empirically depending on what theory is used to describe trade flows. This section will describe the two main theories of trade: Neo-classical trade theory and New trade theory.

Historically, empirical trade flow research was based on **neo-classical trade theory**. In this theory, countries are characterized by their relatively immobile production factors, such as land or labour. Sectors, on the other hand, differ in their intensity of these production factors. Therefore, a country specializes in sectors that are intensive in the factor in which the country is abundant. Alternatively stated, firms or sectors that are intensive in a certain factor choose the country which has that factor in abundance and for a low price. In the end, this leads to a world in which countries specialise in certain goods. In this view, emissions can be seen as a production factor, with countries with stringent environmental regulations being less abundant in this factor and countries with lower environmental stringency being more abundant in this factor. Therefore, emission-intensive sectors will choose to relocate to countries with lower environmental stringency, causing carbon leakage and creating pollution havens. It was also this Neo-classical thinking from which the pollution haven hypothesis originated (Pethig, 1976). Intuitively, these models make sense. However, they are criticised because they fail to explain that countries simultaneously import and export a certain good at the same time, while these flows, in reality, account for a sizeable amount of total trade. Empirical research based on neo-classical trade theory also focuses only on net trade flows, the difference between exports and imports, for each trading partner instead of considering imports and exports separately. Net trade flow models based on neo-classical trade theory have been used in multiple empirical carbon leakage studies (Ederington et al., 2005; Naegele & Zaklan, 2019).

Tinbergen (1962) changed the way trade flows were empirically investigated by introducing the gravity model. Instead of looking at net trade flows only, gravity models allow for modelling bilateral trade flows. Bilateral trade flows include imports and exports as separate observations instead of only including net imports. Gravity equations model bilateral trade flows based on the size of economies, the distance between them and other trade barriers. Models based on the gravity equation are widely known and used for their performance and robustness in explaining bilateral trade flows (Head & Mayer, 2014). Initially, there was no formal economic theory from which the gravity equation was developed. It was only later that the gravity equation was formally derived from theory. The gravity equation can be derived in multiple ways, but it is usually done based on "New trade theory" (Krugman, 1980). Empirical carbon leakage studies have recently begun to rely on gravity models based on New trade theory. Most notably, Aichele and Felbermayr (2015) have developed a gravity model for the carbon content of bilateral trade. A model which was later also adapted and used by Naegele and Zaklan (2019) and Wang and Kuusi (2024). Using a model based on the gravity equation allows the researcher to benefit from using a much larger panel dataset with bilateral trade flows. This results in a multitude of the observations of a net trade flow model and improves the statistical power. Therefore, I will also use a bilateral trade flow model based on the gravity equation. The model will be described in detail chapter 3.

# Chapter 3

# Methodology

The previous chapter has laid the groundwork for the methodology that will be used in this study. This study aims to answer the question: Does the European Union emission trading system cause carbon leakage? The literature review has shown that the research question can be answered by analysing the impact of a measure of environmental stringency, based on the allowance price, on *trade flows* (imports and exports) through regression analysis with panel data. This chapter will go through each of the elements of the method and explain them in detail. First, section 3.1 will describe the empirical strategy that will be followed in this study. It will start with a short reiteration of how carbon leakage can be measured through changes in trade flows. Then, it will go on to present the novel environmental policy stringency measure and the baseline regression model before explaining how the information from the literature review will be used to divide sectors into three groups based on their potential leakage risk. Second, section 3.2 will describe possible identification issues that originate from the methodology, which would limit the possibility of causal inference of the impact of the EU ETS on imports. Third, section 3.3 will describe the data sources and steps that were necessary for the preprocessing of the data. Finally, section 3.4 will provide descriptive statistics of the variables that will be used in the regression.

## 3.1 Empirical Strategy

The empirical strategy of this research is based on the argument from the literature review, in section 2.1, that carbon leakage can be measured through changes in trade. Measuring carbon leakage through trade accounts both for leakage through loss of market share and leakage through relocation of firms. Both of these mechanisms would cause *imports to rise* and *exports to fall*. However, that does not mean that just looking at trade flows alone can show us whether carbon leakage occurs due to the EU ETS. To find out whether carbon leakage occurs due to the EU ETS, we need to estimate the impact of the EU ETS on trade flows while controlling for other factors, which can be done through regression analysis. Regression analysis estimates the impact of a certain variable of interest on a certain outcome variable from data on both these variables. In the case of this study, the variable of interest is the environmental policy stringency of the EU ETS, and the outcome variable are imports and exports to and from the EU. However, as explained in section 2.5, environmental policy stringency is not directly observable, which is why a proxy variable is used. subsection 3.1.1 will explain the environmental stringency variable that will be used in this study. To be able to get results from the regression, first, one needs a mathematical "regression model", which will then be estimated on the dataset using Ordinary Least Squares (OLS) estimation. subsection 3.1.2 will explain the baseline regression model used in this study. The OLS regression will yield a coefficient that explains the impact of the environmental policy stringency of the EU ETS on imports. Then, there is the need to control for other factors that might explain trade flows. To this end, as explained in section 2.2 a panel dataset will be used. That means the data consists of observations on multiple entities over time. Such a panel dataset allows for the inclusion of "fixed effects", which control for unobserved factors that influence trade flows. subsection 3.1.2 will also explain how these fixed effects can control for unobserved factors. I use a panel dataset with bilateral trade flows (where imports and exports are separate observations instead of having net trade flows). Therefore, the dataset consists of observations for combinations of importer, exporter and sector per year. Finally, subsection 3.1.3 will explain how the information from the literature review regarding carbon leakage risk factors and the EU ETS design will be used to identify two groups of sectors with a high potential for carbon leakage.

### 3.1.1 Environmental Policy Stringency Measure

How to measure environmental policy stringency of the EU ETS is one of the most important methodological choices. As explained in section 2.5, two common measures used in the literature both have their flaws. First, a simple EU ETS dummy does not take the recent allowance price into account explicitly and does not allow me to attribute a certain change in trade flows to the increase in allowance price. The second option, a measure based on costs due to the EU ETS, may bias the results against finding carbon leakage because of aggregation bias. Such a measure is affected by the occurrence of carbon leakage because of the heterogeneity of firms within a sector. Using such a cost-based measure, if a large emission-intensive firm relocates outside the EU it will cause the measure of environmental policy stringency to go down, thereby causing lower environmental policy stringency to correlate with higher imports and lower exports. This effect is the exact opposite of what the model should show if carbon leakage occurs. Therefore, I use a novel measure of environmental stringency which tackles the issues present in both common environmental policy stringency measures.

The environmental policy stringency measure that I will use in this study is based solely on the EU ETS allowance price. The allowance price is the same for all sectors. Therefore, in contrast to the sector-specific EU ETS cost measure used by Naegele and Zaklan (2019) and others, my measure does not suffer from the aggregation bias described in section 2.5. Furthermore, the measure improves upon simple EU ETS dummy measures because it takes into account the allowance price explicitly and thereby allows me to attribute changes in imports to changes in the allowance price. As explained in section 2.5, the measure of environmental policy stringency should measure the *difference* in environmental policy stringency between countries, or in other words, the **relative environmental policy stringency (rEPS)**. Therefore, the rEPS measure will be defined by the difference in environmental policy stringency between two countries. Formally, the environmental policy stringency of *one* country will be defined as follows:

$$EPS_{it} = \begin{cases} Peua_t, & \text{if country } i \text{ is in the EU} \\ 0, & \text{otherwise} \end{cases} \tag{3.1}$$

Where $EPS_{it}$ is the environmental policy stringency of country $i$ in year $t$ and $Peua_t$ is the average EU allowance price (in 100 euros) in year $t$. The EPS of a single country can never be negative, because the allowance price is always positive. As explained in section 2.5, I assume the environmental policy stringency of countries outside the EU to be zero because the EU ETS is by far the most stringent environmental policy and because obtaining a measure for all countries would be practically impossible due to time-constraint[1]. Then, the *relative* environmental policy stringency of a pair of countries will be defined as follows:

$$rEPS_{mxt} = EPS_{mt} - EPS_{xt} \tag{3.2}$$

Where $rEPS_{mxt}$ is the relative environmental policy stringency between importer $m$ and exporter $x$ in year $t$. EPS is always either zero (when a country is not in the EU) or positive (when a country is in the EU). Therefore, when a trade flow is an import from a non-EU country to the EU, rEPS will be positive and equal to the EU allowance price,$Peua_t$. On the other hand, when a trade flow is an export from the EU to a non-EU country, rEPS will be negative and equal to $-Peua_t$. Importantly, when a trade flow is either within the EU or from a non-EU country to a non-EU country, rEPS will be equal to zero. The allowance price does not play a role in these cases, and there is no reason for carbon leakage to occur. The next section will explain how the environmental policy stringency measure will be incorporated into the regression model.

### 3.1.2 Baseline Regression Model

For the regression, as explained in section 2.6, I follow the example of earlier authors and use a bilateral trade flow model based on the gravity equation (Aichele & Felbermayr, 2015; Naegele & Zaklan, 2019). Using a model based on the gravity equation allows the researcher to benefit from using a much larger panel dataset with bilateral trade flows. My regression model will differ from the ones used by Aichele and Felbermayr (2015) and Naegele and Zaklan (2019) because I use a different measure of environmental policy stringency and because of the availability of data. The differences between my model and the ones used by other authors will be explained below. The following baseline regression model will be used throughout the rest of this study:

$$ln(y_{mxst}) = \alpha * rEPS_{mxt} + v_{xms} + v_{st} + \epsilon_{xmst} \tag{3.3}$$

Where $ln(y_{xmst})$ is the natural logarithm of the quantity of imports in metric tonnes, from exporter country $x$ to importer country $m$ for sector $s$ in year $t$. $rEPS_{mxt}$ is the main variable of interest, the relative environmental policy stringency between the importer and exporter as defined in the previous section. And $v_{xms}$ and $v_{st}$ are so-called "fixed effects". I will now go through each of the elements of the baseline regression model and explain them in more detail.

As explained in section 2.2, **trade flows in terms of physical quantities** are used as the dependent variable instead of trade flows in embodied carbon or trade flows in value.

[1]The UK left the EU ETS and set up its own UK ETS when it left the EU in 2020. However, I include the UK in the list of EU ETS countries for all years of the analysis, also 2020-2022, because the UK ETS allowance price has been very close to the EU ETS allowance in the period 2020-2022, see also Figure 2.3

Studies use trade flows in embodied carbon because these are believed to most accurately represent carbon leakage (Aichele & Felbermayr, 2015; Naegele & Zaklan, 2019). However, computing trade flows in embodied carbon requires the use of input-output tables, which are only available up to 2020 and would therefore not allow me to include the years with the highest price increase in the regression. Furthermore, input-output tables are only available for a high level of aggregation, where many smaller sectors are grouped together in larger industries. Therefore, I follow the recommendation by Naegele and Zaklan (2019) to use trade flows in quantity if trade flows in embodied carbon are not available. I use the natural logarithm of the import instead of the raw values. Using the natural logarithm reduces the variability in the sizes of the trade flows, which reduces the potential error in the analysis and increases the reliability of the estimates of standard errors, which are used to judge whether a coefficient is statistically significant. The logarithm changes the interpretation of the coefficient $\alpha$. Because of the logarithm, $\alpha$ gives an estimate of the *percentage change* of imports due to a certain change in allowance price instead of a change in imports in absolute terms. Because the quantities of trade flows have a very large variation, see Table 3.1 in section 3.4, a percentage change interpretation makes more sense. For these reasons, Aichele and Felbermayr (2015) and Naegele and Zaklan (2019) also use the natural logarithm in their regression models.

$rEPS_{mxt}$ is the main variable of interest, **the relative environmental policy stringency** between the importer and exporter as defined in the previous section. The goal of the regression analysis is to estimate the coefficient $\alpha$ and thereby estimate the effect of $rEPS_{mxt}$ on imports. If $rEPS_{mxt}$ is positive, it means that importing country $m$ is an EU country and that the exporting country $x$ is a non-EU country. Therefore, a positive coefficient $\alpha$ means that the importer being an EU country increases imports from non-EU countries. Similary, a positive $\alpha$ also means that the exporter being an EU country decreases exports from non-EU countries. Therefore, **a positive estimate for $\alpha$ is in line with the carbon leakage hypothesis**, i.e. that the EU ETS increases imports and decreases exports. The size of $rEPS_{mxt}$ is dependent on the average allowance price for the year $t$. Therefore, a larger $\alpha$ means that the EU allowance price has a larger impact on trade flows.

$v_{xms}$ and $v_{st}$ are so-called "**fixed effects**". As explained in section 2.2, fixed effects are used in regressions with panel data to control for unobserved heterogeneity of the units of observations in the panel dataset. To reiterate, unobserved heterogeneity is the variation in the data which is not explained by the explanatory variable (rEPS in this case). This variation is caused by differences between the units of observation that cannot be directly observed. In the case of bilateral trade flow data the units of observation are combinations of country-pair and sector. It is quite easy to understand that the variation in trade flows between a pair of countries is not *only* influenced by the relative environmental policy stringency between the countries but that many other factors also play a role. These factors can be things such as the distance between countries, size of countries, cultural differences, general time-trends, etc. Fixed effects can be used to control for these factors. The baseline regression model presented above in Equation 3.1.2 includes two sets of fixed effects. First, $v_{xms}$ are country-pair-sector fixed effects accounting for the time-constant sector-specific differences in trade intensity between trading partners. Therefore these fixed effects control for any sectoral factors that influences trade flows between a pair of countries which *do not* change over time. Therefore these country-pair-sector fixed effects will control for distance between countries, country size, historical and cultural aspects, the size of the sector in the countries and any geographical factors (Egger & Pfaffermayr, 2003). Especially country size and distance are two factors that are essential to capture when estimating gravity equations (Head & Mayer, 2014). The other set of fixed effects, $v_{st}$ are sector-year fixed effects capturing sector-specific global changes in trade intensity over time. These sector-year fixed effects will therefore control for global events that occurred during the period of interest, such as the covid-19 pandemic, but also for any sector-level global trends in trade flows, such as a general worldwide increase in trade in the steel sector, for example. Using these two sets of fixed effects has an impact on the interpretation of the coefficient $\alpha$. The fixed effects control for both the time-constant sectoral differences in trade between countries and sector-level global changes in trade flows. Therefore, all the variation that is left in the trade flows is the time-varying difference in trade between two countries in a sector beyond the global trend for that sector. Finally, $\epsilon_{xmst}$ is an error term representing any unobserved factors not captured by $rEPS_{mxt}$ or the fixed effects.

The baseline regression model does not show how the impact of the EU ETS on imports differs per sector. A regression of the baseline model will just give a coefficient $\alpha$ which says something about whether carbon leakage occurred and how large the effects is for *any* sector. To be able to tell for which sectors carbon leakage is the biggest issue, the regression model has to be slightly adapted. How this can be done will be explained in the next section.

### 3.1.3 Dividing Sectors Based on Carbon Leakage Risk

Section 2.3 has explained that the risk of carbon leakage differs per sector and that there are three main factors that influence leakage risk at the sector level: emission intensity, trade intensity and sector mobility (Ederington et al., 2005; Martin et al., 2014). Section 2.3 has already explained that sector mobility will not be taken into account in this study to determine sectors at risk of carbon leakage. The other two factors, emission intensity and trade intensity, are the two most important determinants of carbon leakage risk. Emission intensity increases the costs a sector faces due to the EU ETS because it has more emissions and, therefore, has to buy more allowances. Trade intensity determines how well a sector can pass on the higher costs to consumers and, therefore, how much of the increased costs it has to bear itself. That is also why these are the two factors the European Commission took into account when designing the EU ETS to determine sectors officially "at risk of carbon leakage". The European Commission tries to reduce the risk of carbon leakage by free allocation of allowances. As explained in section 2.4, not all sectors receive equal amounts of free allocation. Sectors on the official "carbon leakage list" receive more free allocation than sectors not on the list. Within a sector, the amount of free allocation a firm receives also differs, depending on that specific firm's emission intensity compared to other firms within the sector. Per sector, the European Commission determined a benchmark, in terms of emissions per kg product, based on the emission intensity of the 10% most emission-efficient firms in the sector. For sectors on the official carbon leakage list, firms within the sector receive 100% of the relevant benchmark in terms of emission allowances. This means that firms that are less efficient than the benchmark still face higher costs and have to buy allowances themselves. Sectors not on the official carbon leakage list received less free allocation, 80% of the relevant benchmark in 2013, decreasing to 30% of the benchmark in 2020.

I will define two groups that have a high potential carbon leakage risk. The sectoral leakage risk factors combined with the free allocation rules together determine how much leakage risk a sector faces. However, it is not immediately clear what sectors, in the end, face the highest risk of carbon leakage. It could be that the free allocation of allowances completely alleviates any risk of carbon leakage for sectors on the official carbon leakage list. But, it could also be that because of the benchmark rule these sectors are still the sectors where leakage occurs. Therefore, the two groups of potential leakage risk sectors are the following:

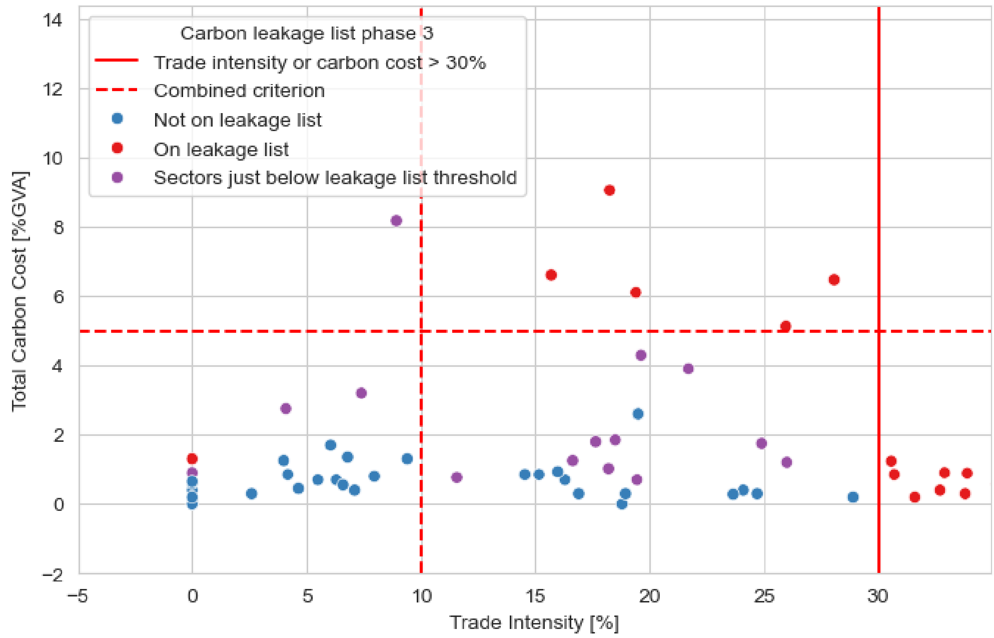
- **Leakage list sectors**, which are the sectors that are on the official leakage list of the European Commission and which have the highest emission intensity and trade intensity but which also receive the most free allocation.
- **Sectors just below the leakage list threshold**: are the sectors that have moderate emission and trade intensity and do not receive the higher level of free allocation because they are not on the official leakage list.

Now, these sectors have to be implemented in the regression model. The goal is to determine whether the risk of carbon leakage is higher for one of these two groups of sectors. To test this, the following model specification will be used:

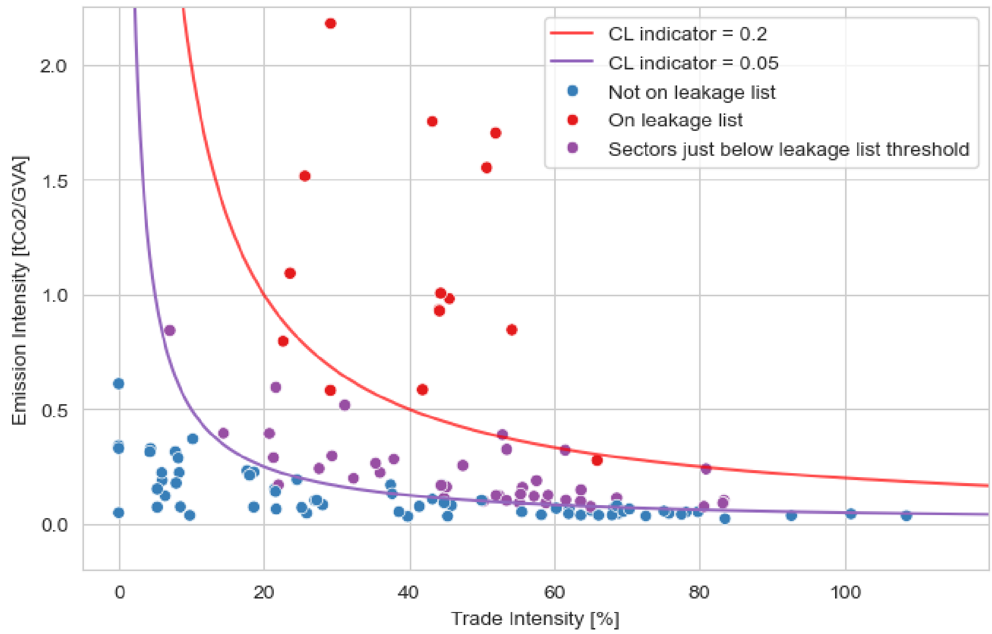
$$ln(y_{mxst}) = \alpha * rEPS_{mxt} + \beta_{LL} * LL_{st} * rEPS_{mxt} + \beta_{bLL} * bLL_{st} * rEPS_{mxt} + v_{xms} + v_{st} + \epsilon_{xmst} \quad (3.4)$$

Where the terms $LL_{st}$ and $bLL_{st}$ are added to the model and interacted with the relative environmental policy stringency measure. $LL_{st}$ and $bLL_{st}$ are dummy variables for the leakage list sectors and the below leakage list threshold sectors, respectively. The variables are equal to 1 if the sector belongs to the corresponding sector group in the corresponding year. Because the official leakage list changed when going from phase three to phase four of the EU ETS, the sectors that belong to these sector groups also change depending on the year. The definition of $LL_{st}$ is quite clear; it is one if the sector is on the leakage list for that corresponding year and zero otherwise. However, for the sectors just below the leakage list threshold, it is necessary to determine what is "just" below the leakage list threshold. The goal is to capture those sectors that have relatively high carbon leakage risk, but that are not on the official leakage list. To determine what "relatively high leakage risk" is, the carbon leakage indicator (CL indicator) will be used, see Equation 2.4.2. This CL indicator is what is used by the European Commission to determine the official sectors at risk of carbon leakage from phase four onwards, as explained in section 2.4. The CL indicator is defined as the product of emission intensity and trade intensity, and therefore, it takes into account that it is the combination of these factors that puts a sector at risk of carbon leakage. For phase four of the EU ETS, sectors were included on the carbon leakage list if their CL indicator is higher than 0.2, therefore, the value of the CL indicator I use to determine sectors "just" below the threshold needs to be below 0.2. To determine the sectors just below the threshold I will initially use a CL indicator cutoff (CL cutoff) value of 0.05. I choose 0.05 to strike a balance between the number of sectors in the group and the strictness of the cutoff. Later in the results section in section 4.2, I will show the impact of choosing different values for the CL cutoff.

Any sectors that are not on the official carbon leakage list for the respective phase, but that do have a CL indicator higher than 0.05 will be included in the group $bLL_{st}$. How this works in practice is shown in Figure 3.1, where the sectors just below the leakage list threshold are shown in purple. A separate figure is shown for phase three and phase four because the sectors on the official leakage list differ for these phases, which also means the sectors just below the threshold differ. The figure for phase three looks a lot less clean than the figure for phase four because for both figures the CL indicator data from the phase four assessment was used (European Commission, 2018b), while the carbon cost and trade intensity data for the phase three figure are from the phase three assessment (European Commission, 2014c). By estimating the regression model from Equation 3.1.3 the coefficients $\beta_{LL}$ and $\beta_{bLL}$ will explain how the impact of relative environmental stringency on imports differs for the different sector groups. A higher coefficient for a sector group indicates that for that sector, relative environmental policy stringency (the allowance price) has a larger effect on imports. This specification changes the interpretation of the coefficient $\alpha$ to now indicate the effect of relative environmental policy stringency on imports for the *reference* sectors. These are the sectors that are *not* part of one of the two sector groups described above. Those sectors are not on the leakage list and have a CL indicator lower than 0.05.




**(a)** Sectors just below the leakage list threshold for phase three




**(b)** Sectors just below the leakage list threshold for phase four

**Figure 3.1**
Sectors just below the carbon leakage list threshold for both phase three and phase four of the EU ETS. For this plot, sectors that have a CL indicator higher than 0.05 but are not on the leakage list are considered "Sectors just below the leakage list threshold"

## 3.2 Identification, Endogeneity and Bias

The previous section has described the methodology that will be used to investigate whether the EU ETS, through the allowance price, has an impact on imports. The aim of the method is be able to answer the question: "Does the EU ETS cause carbon leakage?". However, if the results do give a positive coefficient for $\alpha$, in line with the carbon leakage hypothesis, it does not necessarily mean that it is the EU ETS that caused the changes in imports. This section will explain what elements might bias the results of the regression and how these biases can be accounted for.

As explained in subsection 3.1.2, the baseline regression model includes fixed effects to control for many unobserved factors. Because of these fixed effects, all the variation that is left in the trade flows is the time-varying difference in trade between two countries in a sector beyond the global trend for that sector. In the regression model, only one variable is included besides the fixed effects to capture this remaining variation in the trade flows. This variable is the variable of interest: relative environmental policy stringency (rEPS). In principle, the estimate of the coefficient of rEPS, $\alpha$, will give the effect the rEPS has on imports. However, if there are other factors that correlate with both the measure of rEPS and imports, the estimate of $\alpha$ will be biased, meaning it will not reflect the true impact of the rEPS measure on imports. This issue is called "**endogeneity**" in econometrics. There are many reasons for endogeneity to occur, and thus for the estimate of $\alpha$ to be biased, but the two main ones that might affect this study are the following: reverse causality and omitted variable bias. I will now describe both of these endogeneity concerns and how they can be dealt with.

First, reverse causality would occur if changes in rEPS do not cause variations in imports but the other way around. This could happen when imports at the sector level impact the allowance price. However, this scenario is quite unlikely because none of the sectors is large enough that changes in its imports would significantly influence the general EU allowance price. In fact, most of the demand for EU allowances comes from the electricity sector, which therefore determines the EU allowance price for a large part (Naegele & Zaklan, 2019).

Then, we turn towards omitted variable bias. This form of bias occurs when there exist omitted variables that correlate with both the dependent variable, imports, and the independent variable, rEPS. The existence of such a variable would mean that the estimate of the coefficient $\alpha$ on the rEPS variable does not only reflect the impact of rEPS on imports but also the impact of the omitted variable on the imports. Therefore, it would bias the estimate and make it difficult to claim that the effect on imports is caused by the rEPS variable and, thus, the EU ETS. It is crucial to understand that the omitted variable would have to be correlated with the rEPS variable and with imports *after* accounting for the fixed effects. That means that the omitted variable would have to influence differences in trade between the EU and a non-EU country over time for a sector beyond the global trend for that sector. Only the trade flows to or from the EU with non-EU countries matter in this case because these are the trade flows for which rEPS is not zero. There are some variables which fit this description. Factors such as relative energy, capital, land and labour costs, availability of raw materials, corporate taxation, tariffs, or labour regulation are some possible variables that might influence imports (Sato & Burke, 2021). It is not unlikely that these variables at the same time correlate with the allowance price. There is one factor in particular that provides a challenge: energy prices. From 2020 to the end of 2022, wholesale electricity prices in Europe increased more than fivefold, while it stayed relative stable in other parts of the world (European Commission, 2024e). The US and China, as major trading partners, did not see similar increases in energy prices. This large increase in energy prices happens to coincide with a large increase in EU Allowance price from 2020 to 2022. Therefore, if an effect on imports is found, it could also be the case that it was the energy price increase that caused this effect. Apart from energy prices, there has been a long-term trend of de-industrialisation and a move towards a service economy in the EU and other high-income countries (Sato & Burke, 2021). These long-term trends also affect trade flows, increasing imports to and decreasing exports from the EU for manufacturing and mining & quarrying sectors. It is difficult to attribute this trend in trade flows to any one of these factors separately. As Sato and Burke (2021) note: "With many underlying trends and factors driving trade and investment flows, in reality, it is extremely difficult to attribute changes to trade-embodied emissions to any one specific factor, such as climate policy differences". [2] Therefore, any of the underlying factors that influence this trend might correlate with the allowance price and thereby cause omitted variable bias in my results.

Omitted variable bias can be controlled for by explicitly including the relevant variables in the regression model. However, as explained in the previous paragraph there are many factors that might potentially cause omitted variable bias. Determining which factors correlate with the allowance price would require intensive analysis with a lot of data, and even then, it is difficult to be sure that all relevant factors are covered as other factors that influence imports may still exist. Because of these data requirements, it is unfeasible to include extra control variables in the regression model. Furthermore, if the correlation between a variable and the allowance price is too high, one might run into issues of multicollinearity. This means that, because two variables are correlated, it becomes difficult to attribute an effect of these variables to any of these variables separately. Therefore, the estimation of their coefficients becomes unstable and there is no way to tell whether it is the allowance price or the other variable that causes the effect on imports.

Because it is difficult to identify which variables to control for and to then also obtain the data for these variables, some authors control for the combined effect of these variables by including additional fixed effects in their regression model (Aichele & Felbermayr, 2015; Naegele & Zaklan, 2019; Wang & Kuusi, 2024). They include country-year fixed effects on top of the fixed effects I presented in subsection 3.1.2 [3]. These country-year fixed effects capture the general trends and yearly shocks that influence trade flows to and from a country. Therefore, they can also capture the trends of de-industrialisation and move towards a service economy in the EU, thereby implicitly controlling for the underlying factors. However, because of my novel environmental stringency measure, which does not distinguish between sectors, it is not possible to use these country-year fixed effects. The country-year fixed effects, if included in the model, would cause perfect collinearity with the measure of rEPS, which means that all the variation in the trade flows that would otherwise be captured by the rEPS measure would be captured by the fixed effects and the estimate on rEPS would be zero. This happens

[2] Sato and Burke (2021) discuss trade-embodied emissions specifically, but their argument also holds for the general ability to attribute changes in trade flows to any specific factor.

[3] Aichele and Felbermayr (2015) do not use the sector-year fixed effects I use, but they do include the country-pair-sector fixed effects I use and additionally country-year fixed effects

because the country-year fixed effects already capture all the differences in trade flows to and from the EU from year to year, which makes it impossible to attribute any of the changes to differences in the allowance price between years. There is a way to make it possible to include these country-year fixed effects and not introduce perfect collinearity, which is by including non-EU ETS sectors in the dataset. Currently, the dataset consists only of the manufacturing and mining & quarrying sectors, which are all covered by the EU ETS. Including non-EU ETS sectors in the dataset would make the rEPS measure sector-specific because it should only be non-zero for sectors that are covered by the EU ETS. However, the country-year fixed effects in this case would be determined by all sectors, EU ETS and non-EU ETS, together. Because the rEPS measure then only applies to EU ETS sectors, it would no longer be perfectly collinear with the country-year fixed effects, and therefore, these fixed effects could be included. However, including non-EU ETS sectors presents an issue. Non-EU ETS sectors are mostly service sectors, which do not have any trade in terms of tangible products. Therefore, when performing a regression on imports in terms of physical quantities, as is done for this study, these sectors would not add anything to the analysis and could, therefore, mostly not be included. Even if some sectors could be included, trade from the EU ETS-covered sectors would dominate the data. Therefore, the country-year fixed effects would also account for a lot of the variation in imports in EU ETS sectors, and there would not be much variation to explain in the data for the rEPS measure. In that case, the estimate on the rEPS measure would not accurately reflect the impact of the EU ETS on imports. Therefore, including country-year fixed effects is also not a feasible method of controlling for omitted variable bias.

Using the novel rEPS measure, I have currently not identified a feasible way to control for omitted variable bias and the general trend of de-industrialisation in the EU. However, it should be noted that this issue arose after identifying and accounting for the aggregation bias problem in other carbon leakage studies. The novel environmental policy stringency measure, based on the allowance price, is used because the emission cost measures used by other studies might cause aggregation bias, as explained in section 2.5. Therefore, the search for an alternative method to remove a potential source of bias resulted in a new potential source of bias. I will continue with the method described in this chapter and provide recommendations for further improvements in section 5.1. Importantly, the results from the analysis can still provide valuable insight. They will show whether trade flows to and from the EU for EU ETS sectors indeed changed beyond the global trend for those sectors in line with the increase in allowance price. The expectation is, given the de-industrialisation trend, that there will be a rise in imports to and a decrease in exports from the EU for manufacturing and mining & quarrying. Apart from the baseline results, the results regarding the carbon leakage risk groups will also provide valuable insight. They will show whether the association between the allowance price and imports is stronger for certain sectors than it is for others. If there is a strong correlation between the allowance price and imports for the group of sectors just below the leakage list, it may still indicate that the sharp thresholds had an influence on the risk of carbon leakage. Furthermore, even if changes in imports cannot be attributed only to changes in allowance price because of omitted variable bias, the results on the sector groups will still show for which sectors the change in imports was largest from 2013 to 2022. section 4.1 and section 4.2 will describe the results of the baseline regression and the sectoral leakage risk groups, respectively. section 4.3 will provide a discussion on the interpretation of these results in light of the identification issues described in this section.

## 3.3 Data

The previous two sections have explained the empirical strategy that will be used for this study and the ways in which the methodology might cause some bias in the results. Before the results can be described, it is important to understand what data is used in the regression analysis. No data source is perfect and several issues arise when datasets have to be combined, which is why many preprocessing steps were taken to prepare the data for analysis. This section will describe the data sources, their formats and the necessary preprocessing steps. Subsection subsection 3.3.1 will deal with the trade data, subsection 3.3.2 will deal with the data for the EU allowance price and subsection 3.3.3 will deal with the carbon leakage risk data from the carbon leakage assessments by the European Commission. Finally, subsection 3.3.4 will describe how the data in different sector classifications were combined into one common sector classification.

### 3.3.1 Trade Data

The main outcome variable in the regression is the trade flow between two countries. These trade flows have to be bilateral, meaning imports and exports are separate observations, and at the sector level. This study will obtain the trade flow data from the BACI dataset by CEPII, which uses the United Nations Comtrade database as its source data (Gaulier & Zignago, 2010). Using the Comtrade database directly is not advisable because there are many cases of missing trade flows in the dataset. BACI corrects for these missing trade flows by combining the data from both the importer and the exporter of a trade flow, which is possible because each country reports its trade flows separately to Comtrade. BACI is one of the most detailed trade datasets, having trade flows at the product level (5000 products) for 200 countries and also including trade flow in quantities instead of only in value. Moreover, and essential for the goal of this study, it is one of the only datasets of this quality which has very recent data (2022 being the most recent year at the time of writing (May 2024)).

The BACI dataset comes in different versions depending on the version of the statistical classification system of products. Products in BACI are classified according to the Harmonized System (HS) classification. The Harmonized System is a statistical classification system developed and maintained by the World Customs Organisation, which classifies products based on a 6-digit code. It is the most common product classification used worldwide. The HS system is updated every five years to keep up-to-date with developments in products and trade worldwide. Per update, most of the codes stay the same, while some codes are changed because products are included in other codes, divided over multiple codes, added or removed. Because of these updates, an old version of the system cannot be converted easily into newer versions of the system, whereas the other way around is possible. Therefore, the newest version of the BACI trade data in the HS22 (2022 version) classification only includes the years from 2022 onwards. An older version does include all years from that year onwards up to and including the most recent year (2022 now). So version HS02, for example, includes all years from 2002 to 2022. However, an older version suffers a bit in quality because it needs to convert all recent data reported in recent HS revisions to the older HS revision. Therefore, to strike a balance between data-quality and having a large enough data range I use the HS12 version of BACI. This allows me to include every year from phase three (2013-2020) and phase four (from 2020 onwards) of the EU ETS.

The complete BACI dataset contains more than 200 countries, many of which are very small and do not account for a significant amount of global trade. Using all these countries in the regression analysis may lead to noise in the data and unreliable results, especially because I use a logarithmic form of the dependent variable, which reduces any absolute size effects and increases the relative importance of small trade flows. Therefore, I remove the smallest countries from the dataset, in terms of the average total imports from 2013 to 2022, keeping only the 100 largest countries. Later, I will test the robustness of the results by using datasets with only the 75, 125, and 150 largest countries, as well as the full dataset. Furthermore, I removed all trade flows from the dataset that are smaller than 1000kg. These trade flows are so small that changes in them would create large changes when using the logarithm, which would give them a lot of power in the regression, while their real-life importance is negligible.

### 3.3.2 EU ETS Allowance Price Data

In this study, the EU allowance price is used in the measure of relative environmental policy stringency (rEPS). The allowance price data is obtained from the allowance price explorer by the International Carbon Action Partnership (ICAP) [4]. ICAP provides a daily EU ETS spot carbon allowance price in euros/t$CO_2$ from the start of the EU ETS in 2005 to 2024. The daily prices need to be converted to yearly average prices to correspond to the other yearly data used in the regression. I convert to average yearly prices by computing the arithmetic mean of the daily allowance prices; the result of this conversion can be seen in Figure 3.2.

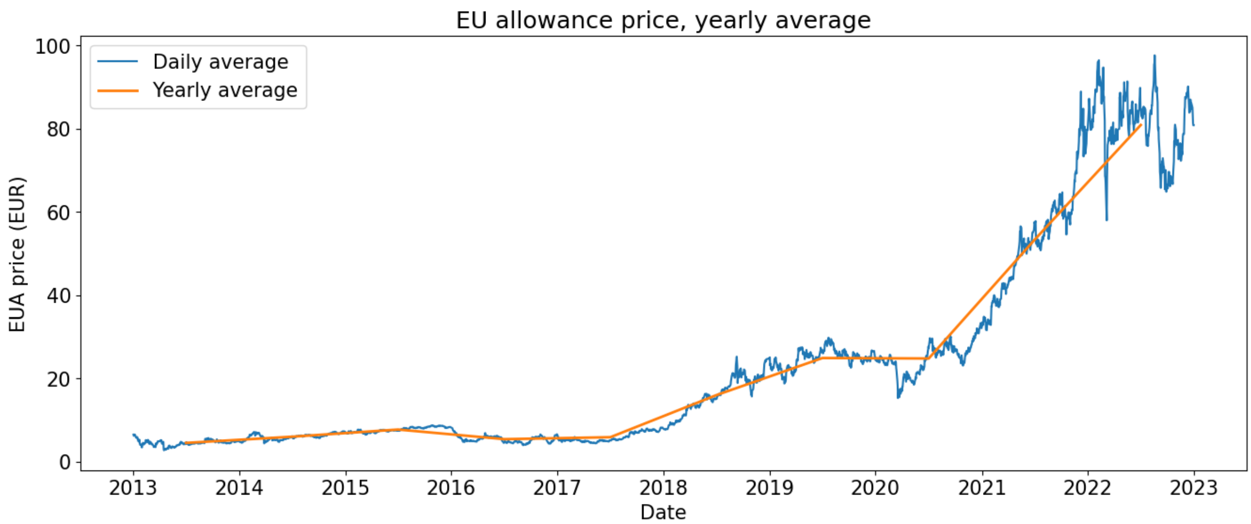



**Figure 3.2**
EU allowance price conversion from daily average prices to yearly average prices

Furthermore, the allowance price is provided by ICAP in nominal form. However, to better reflect the cost experienced by firms due to the EU ETS, I correct for inflation and convert the nominal prices to real prices using the Harmonized Index of Consumer Prices by Eurostat, with 2015 as the base year. [5]. Figure 3.3 shows the result of the conversion from nominal to

[4]https://icapcarbonaction.com/en/ets-prices
[5]https://ec.europa.eu/eurostat/databrowser/view/prc_hicp_midx/default/table?lang=en&category=prc.prc_hicp

real prices.

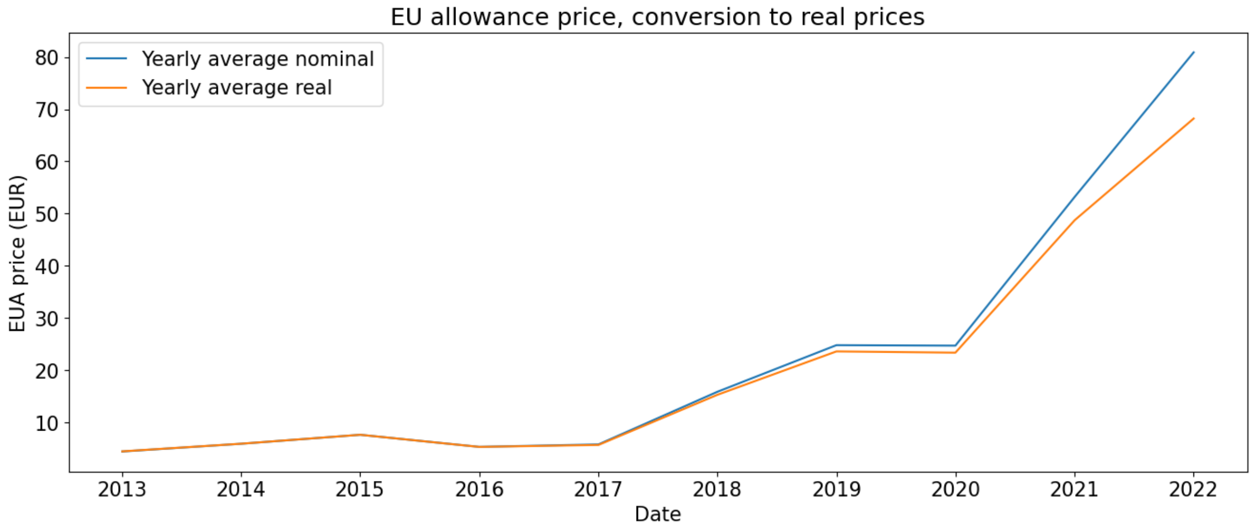



**Figure 3.3**
Yearly EU allowance price conversion from nominal to real (2015) prices

### 3.3.3 Sectoral Carbon Leakage Risk Data

The data that is used to divide sectors into groups based on leakage risk, as described in subsection 3.1.3, comes from carbon leakage assessments performed by the European Commission (EC). The EC performed these assessments to determine which sectors should be on the official carbon leakage list and which sectors should not. To determine the sectors on the official carbon leakage list for phase three, I use the data from the corresponding carbon leakage assessments (European Commission, 2014c). The document provides info on total emission costs as a percentage of GVA as well as trade intensity. Therefore, the carbon leakage criteria from phase three can be applied to find the sectors on the official carbon leakage list for phase three. Similarly, for phase four, I use the CL indicator data from the carbon leakage assessments of phase four to determine sectors on the official leakage list for phase four (European Commission, 2018b). For both phase three and phase four there were also sectors added to the carbon leakage list based on qualitative criteria (European Commission, 2014a, 2019a). I manually add these sectors to the group of sectors on the leakage list for both phases. Then, to determine the sectors just below the leakage list threshold, I use the same CL indicator data from the phase four assessment. It is important to note that I use the CL indicator data from the *phase four* assessment to determine the sectors just below the leakage list threshold for *both phases*. I use the phase four detailed assessment data because the phase three detailed assessment did not include the CL indicator (European Commission, 2014c). The detailed assessment of phase four was carried out in 2014, which means that the data is by no means unsuitable for determining the leakage risk of the sectors during phase three (2013-2020). Since the largest part of the data covers phase three, I consider it justified to use this CL indicator throughout the entire range of years. Furthermore, I assume that sector's emission intensity and trade intensity, and thus the CL indicator and leakage risk, are relatively stable throughout the period of interest. At least to the degree that throughout the period of interest, the CL indicator provides an accurate enough indication of sectoral leakage risk.

### 3.3.4 Conversion of Statistical Classifications to a Common Sector-level Classification

The BACI trade data and the European Commission leakage risk data each come in different statistical classifications. The BACI dataset comes in the product-level Harmonized System (HS) classification, which divides all trade activity into 5000 products. The carbon leakage risk data comes in the EU's sector-level Statistical Classification of Economic Activities in the European Community revision 2 (NACE2) classification (European Commission, 2014c, 2018b). The NACE system classifies economic activities into 615 sectors using a 4-digit code. Because I want to use both datasets in the same regression, I need to convert them to a common sector-level classification. The objective of this conversion is to limit the amount of data loss and, at the same time, retain a high level of disaggregation.

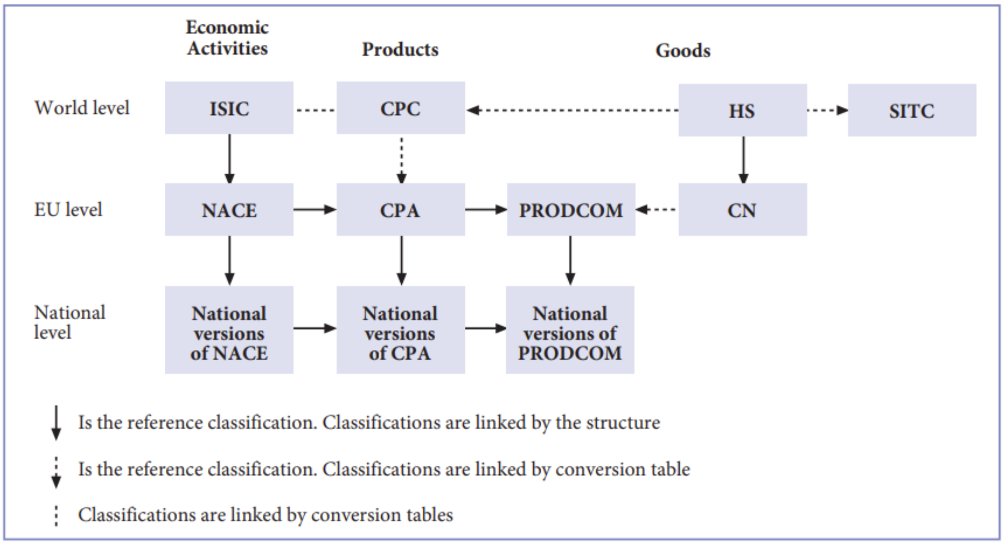



**Figure 3.4**
The international system of economic classifications. From *NACE Rev 2, Statistical classification of economic activities in the European Community*(p.13) by Eurostat, 2009, Eurostat Methodologies and Working Papers

Figure 3.4 shows the most common statistical sector- and product-level classification systems in the EU and the rest of the world. The HS product-level trade flow data needs to be converted to a sector-level classification. To this end, the trade flow data will be converted to the International Standard Industrial Classification of All Economic Activities (ISIC) classification by the United Nations. ISIC is a classification of economic activities into sectors, very similar to NACE. Because the trade flow data comes in the older HS12 classification, it cannot be converted to the most recent ISIC Rev. 4 (ISIC4) classification, instead, it needs to be converted to the older ISIC Rev. 3 (ISIC3) classification, which will be done using a conversion table from World Integrated Trade Solutions by the World Bank [6]. Ideally, one would then want to convert the trade flow data from ISIC3 to the NACE2 classification of the

[6] https://wits.worldbank.org/product_concordance.html

leakage risk data such that the results will be presented in terms of the sector classification used by the EU. However, although possible, that would lead to too much data loss because the classification from the older ISIC3 to the newer NACE2 is poorly defined. Therefore, the leakage risk data will also be converted to ISIC3 classification instead. The 5000 products of the BACI trade data (in HS classification) are mapped onto 145 ISIC3 sectors. When multiple products are mapped onto one sector, the trade flows of these data points are added together to obtain the trade flow of the sector. When one product is mapped onto more than one sector, the trade flow is divided equally over these sectors.

The trade intensity, emission intensity and CL indicator data from the carbon leakage assessments are also converted from the NACE2 sector classification to the ISIC3 sector classification. The carbon leakage assessments contain data on 236 sectors according to the NACE2 classification. These sectors are converted to the ISIC3 classification via ISIC4 and ISIC3.1 using conversion tables from the United Nations Statistics Division [7]. The conversion results in a dataset of 139 sectors in the ISIC3 classification. However, these are not the exact same sectors as the ones in the trade data after the conversion. Therefore, there are two more steps needed to obtain the final list of sectors. First, any sectors that are present in one of the datasets and not in the other dataset are removed from both datasets. Second, and finally, only sectors in the manufacturing and mining & quarrying sectors are retained since these are the ones that are covered by the EU ETS. These steps combined result in a list of **116 sectors, in the manufacturing and mining & quarrying industries** in the regression data. A full list of sectors included in the regression analysis can be found in Table B.1 in Appendix B.

## 3.4 Descriptive Statistics

Table 3.1 below shows some descriptive statistics for the variables used in the regression. These descriptive statistics result from the baseline dataset that is used for most of the regressions. As explained in previous sections, this dataset consists of data on the 116 ISIC3 sectors that are both in the trade flow data and in the leakage assessment data. Furthermore, any trade flows smaller than 1000kg are removed and only the largest 100 countries are kept. This results in a dataset with 4.3 million observations.

**Table 3.1**
Descriptive Statistics

| Statistic | Mean | Median | St. Dev. | Min | Max | N |
|---|---|---|---|---|---|---|
| **Regression variables** | | | | | | |
| Relative EPS, $rEPS_{mxt}$ [100 EUR] | −0.021 | 0.000 | 0.193 | −0.682 | 0.682 | 4,305,537 |
| Logarithm of trade flow, $ln(y_{mxst})$ | 4.933 | 4.657 | 2.967 | 0.001 | 20.427 | 4,305,537 |
| Leakage list dummy, $LL_{st}$ | 0.616 | 1 | 0.486 | 0 | 1 | 4,305,537 |
| Just below leakage list dummy, $bLL_{st}$ | 0.155 | 0 | 0.362 | 0 | 1 | 4,305,537 |
| **Additional variables for reference** | | | | | | |
| Trade flow, $y_{mxst}$ [1000kg] | 28,568.340 | 105.309 | 1,463,735.000 | 1.001 | 743,642,868.000 | 4,305,537 |
| EU ETS exporter dummy | 0.428 | 0 | 0.495 | 0 | 1 | 4,305,537 |
| EU ETS importer dummy | 0.329 | 0 | 0.470 | 0 | 1 | 4,305,537 |

[7] https://unstats.un.org/unsd/classifications/Econ

A couple of points from Table 3.1 are interesting to point out. First of all, the mean of the relative environmental policy stringency variable is slightly negative, but relatively close to zero. Why this is the case can be seen in Figure 3.5. Around 55% of trade flows are either outside the EU ETS or within the EU ETS, meaning they have a relative environmental policy stringency of zero. Therefore, these trade flows are not used in estimating the coefficient of the rEPS variable. However, these trade flows are important in determining the sector-year fixed effects. Table 3.1 furthermore shows that the variation in trade flow quantities for the raw trade flows is indeed very large, which provides justification for the use of the logarithm since the large values would otherwise dominate the regression results. It can be seen that the variation in the logarithm of trade flows is much smaller. Finally, the leakage risk dummies give an indication of how large the sectoral leakage risk groups are. The mean value of the leakage list dummy, $LL_{st}$, indicates that almost 62% of observations concern a sector that is on the official leakage list for the respective year. On the other hand, the mean value for the dummy for sectors just below the leakage list indicates that around 15% of observations concern a sector that is just below the leakage list. The descriptive statistics table does not show any anomalies that should be taken care of. Therefore the data as presented here can be used in the regression. The next chapter will provide the results from the regression and discuss their meaning.

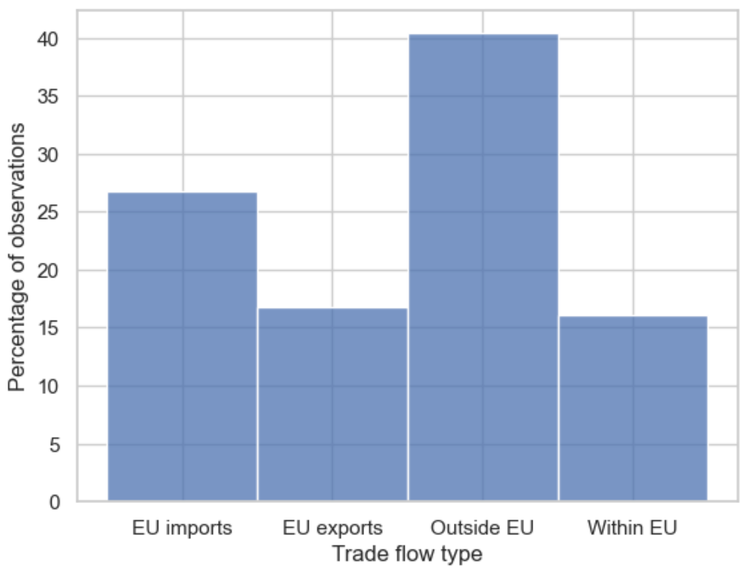



**Figure 3.5**
Percentage of total trade flow observations per type. "EU imports" are imports by an EU country from a non-EU country, "EU exports" are exports by an EU country to a non-EU country, "Outside EU" are trade flows between two non-EU countries and "Within EU" are trade flows within the EU.

# Chapter 4

# Results and Discussion

The previous chapter has presented the methodology that will be used to answer the main research question of this study: Does the EU ETS cause carbon leakage? As explained in chapter 3, the results are obtained through ordinary least squares (OLS) regression using data on bilateral trade flows across a panel of importers, exporters, sectors, and years. This chapter will present and discuss the results of the regression analysis. First, section 4.1 will give the results from the baseline regression model, as well as some robustness tests of these results using modified datasets. Second, chapter 3 has also explained how sectoral carbon leakage risk will be incorporated into the analysis by distinguishing two sector groups with a high potential for carbon leakage. Therefore, section 4.2 will present the results from this analysis and show that it does matter whether a sector is on the official carbon leakage list. Both sections will also describe how robust the results are to using different model specifications or slightly modified data. Finally, section 4.3 will discuss the validity and meaning of the results in light of the identification issues presented in section 3.2.

## 4.1 Baseline Regression Results

This section presents the results from the baseline regression, which only includes the relative environmental stringency variable and importer-exporter-sector and sector-year fixed effects, as shown in Equation 3.1.2. As explained in section 3.3, the baseline regression will be performed on a dataset with all trade flows smaller than 1000kg filtered out and only keeping the 100 largest countries. Table 4.1 shows the result from the baseline regression (column 1) as well as three other specifications with fewer fixed effects (columns 2-4). The specifications with fewer fixed effects are included to show the importance of using the fixed effects in the regression model.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | |
|---|---|---|---|---|
| Model: | (1: Baseline) | (2) | (3) | (4) |
| *Variables* | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1780*** | 0.1328*** | 0.3090*** | 0.3473*** |
| | (0.0056) | (0.0055) | (0.0309) | (0.0074) |
| Constant | | | | 4.940*** |
| | | | | (0.0014) |
| *Fixed-effects* | | | | |
| country-pair-sector | Yes | Yes | | |
| sector-year | Yes | | Yes | |
| $R^2$ | 0.8985 | 0.8977 | 0.1535 | 0.0005 |
| Observations | 4,305,537 (all columns) | | | |

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table 4.1**
Regression results of the baseline regression model

First, the main thing of interest from Table 4.1 is the coefficient on the policy stringency, $rEPS_{mxt}$, which corresponds to $\alpha$ in Equation 3.1.2. To reiterate, this coefficient gives the effect of relative environmental policy stringency on imports. $rEPS_{mxt}$ is defined such that an import from a non-EU country to the EU has a positive relative environmental stringency. It can be seen in the table that the coefficient on $rEPS_{mxt}$ is positive, with a value of 0.1780, and statistically significant at the 1% level. Because the *logarithm* of the trade quantity is used as the dependent variable and because $rEPS_{mxt}$ is measured in *100 euros* the interpretation of the coefficient is as follows: Keeping all other factors fixed, an EU allowance price increase of 100 euros is associated with an increase in imports to the EU of 17.8 %. The regressions with different fixed effects specifications show that the choice of fixed effects greatly impacts the estimates of $rEPS_{mxt}$. Especially the addition of the country-pair-sector fixed effects increases the $R^2$ to around 0.9, meaning the fixed effects explain around 90% of the variation in the logarithm of the trade flows. This also makes intuitive sense as the country-pair-sector fixed effects control for important determinants of imports such as country size, distance between countries and the size of the sector in the countries. Therefore, it is definitely important to include these country-pair-sector fixed effects in the other regressions as well. The sector-year fixed effects explain less of the final effect than the country-pair-sector fixed effects, but they still have some influence. Furthermore, there are good theoretical reasons why they should be included, for example because they control for the global shock of covid-19 at the sector level. Therefore, all further model specifications discussed in this chapter will use both exporter-importer-sector and sector-year fixed effects. section 4.3 will discuss what can be said about the causal relationship between the allowance price and imports in light of the potential omitted variable bias. First, the next subsection will show the robustness of the results from the baseline regression using modified datasets.

### 4.1.1 Robustness of the Baseline Results

It is important to establish whether the results from the baseline regression are robust to slight modifications in the data. If the results are not robust, one must be very careful inferring conclusions from them. Therefore, this section will describe the robustness of the baseline regression to differences in terms of the number of countries and the years that are included in the data.

First, Table 4.2 shows the robustness of the baseline regression results to removing different numbers of small countries. It can be seen that removing more or less small countries does not change the direction or general magnitude of the coefficient on $rEPS_{mxt}$, especially for the data with 75 or more countries. Only the regression on the data with just the 50 largest countries shows an increase in the coefficient on $rEPS_{mxt}$. However, at this point, many countries have been removed from the data, including some of the smaller EU ETS countries such as Denmark, Greece, Hungary, and Bulgaria. Therefore, the specification with only 50 countries no longer represents the total picture of the impact of the EU ETS on trade. Second, Table 4.3 shows whether the results from the baseline are robust to removing some years from the analysis. It can be seen that removing the years 2013-2015 from the data lowers the estimate on the coefficient of $rEPS_{mxt}$, but the changes are relatively small. However, removing the years 2020-2022 has a larger impact on the estimates. Especially when 2021 and 2022 are removed, the estimate of $rEPS_{mxt}$ becomes almost twice as large as the baseline. It is not immediately clear why the estimate changes considerably when later years are removed, but it is likely that it has to do with the fact that the allowance price also increased a lot during these years. Overall, the main finding from these robustness tests is that although the magnitude of the estimates changes in some cases, the overall direction and significance of the estimate are very robust. In each of the robustness tests, the estimate on $rEPS_{mxt}$ is strictly positive and usually between 0,15 and 0.18 and up to 0.28 in some extreme cases, all of which are significant at the 1% level. In the coming regressions, data from the 100 largest countries and all years will be used unless otherwise specified.

Finally, the findings are also robust to various other specifications, the results of these tests can be found in Appendix A. Table A.1 shows the robustness of the results by only looking at changes in the intensive margin, i.e. changes in quantity over time for existing trade flows instead of the emergence of new trade flows. To this end, the dataset used for this robustness test only includes combinations of importer, exporter and sector that are observed in each year. Second, Table A.2 shows the results of the regression on data with the 5 largest countries removed. Finally, Table A.3 shows the robustness of the results to removing different numbers of large sectors from the data. These additional robustness tests confirm the findings from this section that the results of the baseline regression are robust to changes in the data.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | | | |
|---|---|---|---|---|---|---|
| Number of countries: | 50 | 75 | 100 | 125 | 150 | all(228) |
| *Variables* | | | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.2390*** | 0.1835*** | 0.1780*** | 0.1809*** | 0.1853*** | 0.1774*** |
| | (0.0084) | (0.0063) | (0.0056) | (0.0052) | (0.0050) | (0.0047) |
| $R^2$ | 0.9106 | 0.9040 | 0.8985 | 0.8960 | 0.8934 | 0.8927 |
| Observations | 1,683,060 | 3,162,327 | 4,305,537 | 5,119,973 | 5,852,907 | 6,627,471 |

*Clustered (country-pair-sector) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table 4.2**
Baseline regression results on datasets with different amounts of smallest countries removed. The "Number of countries" shown above the columns is the number of countries left after removing small countries. All regressions include country-pair-sector and sector-year fixed effects

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | | | | |
|---|---|---|---|---|---|---|---|
| Included years: | '13-'22 | '14-'22 | '15-'22 | '16-'22 | '13-'21 | '13-'20 | '13-'19 |
| *Variables* | | | | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1780*** | 0.1685*** | 0.1655*** | 0.1528*** | 0.2133*** | 0.2810*** | 0.2373*** |
| | (0.0056) | (0.0055) | (0.0055) | (0.0055) | (0.0080) | (0.0149) | (0.0163) |
| $R^2$ | 0.8985 | 0.9042 | 0.9103 | 0.9172 | 0.9039 | 0.9089 | 0.9145 |
| Observations | 4,305,537 | 3,894,588 | 3,477,826 | 3,050,730 | 3,873,708 | 3,435,265 | 3,004,104 |

*Clustered (country-pair-sector) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table 4.3**
Baseline regression results on datasets with some years removed. All regressions include country-pair-sector and sector-year fixed effects

## 4.2 Sectoral Carbon Leakage Risk Groups results

The previous chapters have highlighted the importance of distinguishing between different groups of sectors when analysing carbon leakage because of large differences in carbon leakage risk between sectors. Subsection 3.1.3 has explained how two groups with a high potential carbon leakage risk are defined using dummy variables: sectors on the official leakage list ($LL_{st}$), and sectors just below the leakage list $bLL_{st}$. To reiterate, the sectors just below the leakage list are defined as sectors that have a CL indicator higher than 0.05 but are not on the leakage list. The sector dummies are included in the regression model as an interaction with the relative environmental policy stringency measure, as shown in Equation 3.1.3. Table 4.4 shows the results from this regression. The first column shows the baseline model without dummies, columns 2 and 3 add the just below leakage list and leakage list dummies to this baseline, respectively, and column 4 shows the results from the regression with both dummies included in the model. Column 4, therefore, corresponds to the model from Equation 3.1.3. A positive coefficient for the interaction term of a dummy indicates that for that group of sectors the effect of rEPS on imports is larger. It is important to understand that the interpretation of the coefficient for $rEPS_{mxt}$, in the top row, changes depending on which dummies are included. In each of the cases, the top row coefficient indicates the effect of rEPS on imports for sectors that are *not* part of one of the dummy groups. So, in the case of column 3, the coefficient in the top row can be interpreted as the effect of rEPS on imports for *any* sector *not* on the leakage list. In the case of column 4, the coefficient in the top row corresponds to any sector that is both not on the leakage list and not just below the leakage list, i.e. "low risk" sectors with a CL indicator below 0.05.

The results in Table 4.4 show some interesting things. First of all, the interaction of $LL_{st}$ with rEPS in models 3 and 4 has a positive coefficient which is statistically significant at the 1% level. The size of the coefficient is also practically relevant. In model 4, the coefficient of 0.0844 indicates that a 100 euro increase in the allowance price is associated with an 8.4% *larger* change in imports for sectors on the leakage list compared to the reference group of low-risk sectors. Interestingly, the effect is the opposite for sectors just below the leakage list. For these sectors, the effect of $rEPS_{mxt}$ on imports is smaller than for the reference group of low-risk sectors. This effect, too, is statistically significant at the 1% level. To emphasize this latter point: the effect of $rEPS_{mxt}$ on imports is larger for sectors with the lowest CL indicator, so the lowest emission and trade intensity, than it is for the sectors that have a moderate CL indicator and fall just outside the official leakage list. The results from model 4 are also shown in Figure 4.1 below. In the graph, the result is clearly visible: the association between the allowance price and imports is largest for sectors on the official carbon leakage list and smallest for the sectors just below the leakage list. What is also noticeable in the graphs is that the confidence intervals are all very narrow, indicating the statistical significance of the results.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| *Variables* | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1780*** | 0.2053*** | 0.1637*** | 0.1795*** |
| | (0.0056) | (0.0068) | (0.0053) | (0.0068) |
| *Interactions* | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | | -0.0710*** | | -0.0346*** |
| | | (0.0086) | | (0.0096) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | | | 0.1015*** | 0.0844*** |
| | | | (0.0104) | (0.0115) |
| $R^2$ | 0.8985 | 0.8985 | 0.8985 | 0.8985 |
| Observations | 4,305,537 (all columns) | | | |

*Clustered (country-pair-sector) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table 4.4**
Results of regression including interactions with sectoral leakage risk dummies. These regressions all use a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold. All regressions include country-pair-sector and sector-year fixed effects

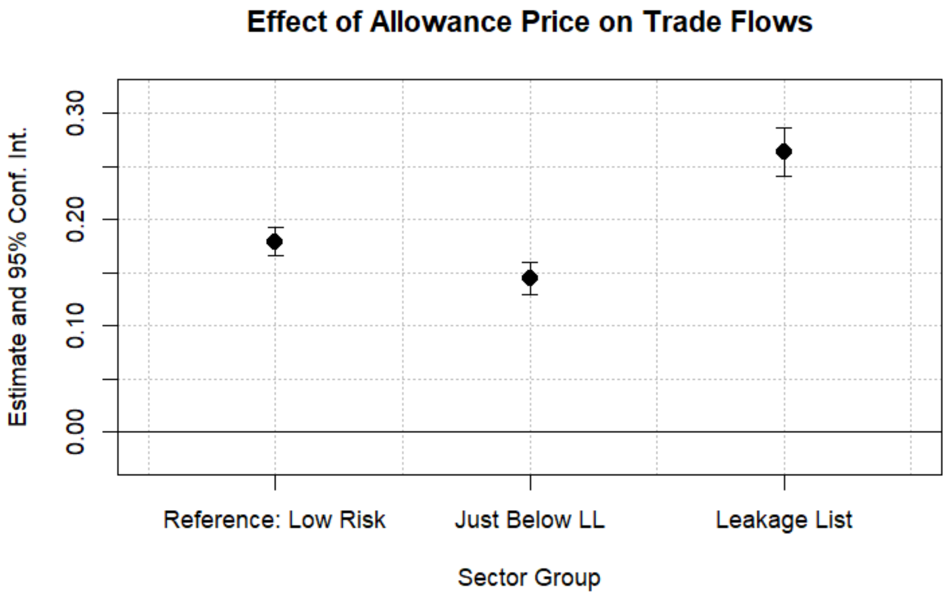



**Figure 4.1**
Result of the regression for the two carbon leakage risk sector groups and the reference "low risk" group. The regression uses a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CL indicator cutoff for $bLL_{st}$ : | 0.01 | 0.01 | 0.025 | 0.025 | 0.05 | 0.05 | 0.1 | 0.1 |
| *Variables* | | | | | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.2717*** | 0.3859*** | 0.2514*** | 0.2318*** | 0.2053*** | 0.1795*** | 0.1807*** | 0.1633*** |
| | (0.0113) | (0.0387) | (0.0096) | (0.0144) | (0.0068) | (0.0068) | (0.0057) | (0.0055) |
| *Interactions* | | | | | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | -0.1119*** | -0.2276*** | -0.1016*** | -0.0803*** | -0.0710*** | -0.0346*** | -0.0346** | 0.0042 |
| | (0.0100) | (0.0391) | (0.0089) | (0.0152) | (0.0086) | (0.0096) | (0.0162) | (0.0167) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | | -0.1236*** | | 0.0298* | | 0.0844*** | | 0.1021*** |
| | | (0.0404) | | (0.0177) | | (0.0115) | | (0.0106) |
| $R^2$ | 0.8985 | 0.8985 | 0.8985 | 0.8985 | 0.8985 | 0.8985 | 0.8985 | 0.8985 |
| Observations | 4,305,537 (all columns) | | | | | | | |

*Clustered (exporter-importer-ISIC3) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table 4.5**
Results of regression including interactions with sectoral leakage risk dummies for different CL indicator cutoff values. All regressions include country-pair-sector and sector-year fixed effects

The regressions in Table 4.4 all use a cutoff point of 0.05 for the CL indicator to determine sectors just below the leakage list ($bLL_{st}$). This value is chosen to strike a balance between the number of sectors in the group, not too few and not too many, and the strictness of the cutoff. Table 4.5 shows the impact of changing the CL cutoff value. Only the models that include $bLL_{st}$ are shown in the table because the baseline and the model with only the $LL_{st}$ interaction do not change when the CL cutoff is changed. It can be seen that the results are quite sensitive to changes in the CL cutoff value. When a very low CL cutoff of 0.01 is used the regression shows some unexpected behaviour, with the coefficient on the reference group being much larger than the coefficients for both groups of sectors that should have higher carbon leakage risk. However, with such a low CL cutoff value, the reference group consists of only the 3 sectors, one of which is responsible for 80% of the data points in the group. Therefore, this result is dominated by that single sector. Similarly, when a high CL cutoff value of 0.1 is used the coefficient for the just below leakage list sectors becomes statistically insignificant. That is most likely because, at that point, there are only a few sectors that fall between the official leakage list and the CL cutoff point, which makes it more difficult to detect an effect if it exists. Overall, both regressions with moderate CL cutoff values, 0.05 and 0.025, show similar results in terms of the direction of the coefficient on the interaction term with sectors just below the leakage list. Furthermore, all regressions indicate a higher coefficient for sectors on the leakage list than for sectors just below the leakage list. section 4.3 will further discuss the findings from both tables presented in this section and whether they provide a reason to believe that carbon leakage has occurred for some sectors due to the EU ETS.

### 4.2.1 Robustness of the Sectoral Carbon Leakage Risk Groups Results

This section will describe the robustness of the results for the sectoral carbon leakage risk groups to differences in data. Table 4.6 shows the robustness of the results to excluding

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | | | | |
|---|---|---|---|---|---|---|---|
| Included years: | '13-'22 | '14-'22 | '15-'22 | '16-'22 | '13-'21 | '13-'20 | '13-'19 |
| *Variables* | | | | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1795*** | 0.1705*** | 0.1655*** | 0.1544*** | 0.2256*** | 0.2444*** | 0.1770*** |
| | (0.0068) | (0.0067) | (0.0067) | (0.0066) | (0.0097) | (0.0385) | (0.0416) |
| *Interactions* | | | | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | -0.0346*** | -0.0302*** | -0.0238** | -0.0219** | -0.0549*** | -0.0798 | 0.0067 |
| | (0.0096) | (0.0094) | (0.0092) | (0.0091) | (0.0133) | (0.0636) | (0.0690) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | 0.0844*** | 0.0788*** | 0.0860*** | 0.0781*** | 0.0320** | 0.0614 | 0.0816* |
| | (0.0115) | (0.0114) | (0.0112) | (0.0110) | (0.0137) | (0.0421) | (0.0456) |
| Observations | 4,305,537 | 3,894,588 | 3,477,826 | 3,050,730 | 3,873,708 | 3,435,265 | 3,004,104 |
| $R^2$ | 0.8985 | 0.9042 | 0.9103 | 0.9172 | 0.9039 | 0.9089 | 0.9145 |

*Clustered (exporter-importer-ISIC3) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table 4.6**
Results of regression including interactions with sectoral leakage risk dummies with certain years removed to test robustness. These regressions all use a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold. All regressions include country-pair-sector and sector-year fixed effects

specific years from the dataset. It can be seen that the results for the leakage risk groups of sectors are robust to excluding the early years 2013-2015 from the dataset. However, the results are quite sensitive to removing years 2020-2022 from the data. When these years with large changes in allowance price are excluded, the coefficients for the interaction of the leakage risk dummies with the rEPS measure change in magnitude and lose significance. These results again highlight the importance of including the later years, with large allowance price increase, in the analysis. I also tested the robustness of the sectoral leakage risk groups with respect to the number of countries in the dataset, ranging from only 50 countries to the full dataset of 228 countries. The results are very robust to differences in the number of countries with hardly any changes in terms of the estimated coefficients. Therefore, the results from this robustness test, in Table A.4, are located in Appendix A. This is also where the results of other robustness tests are located. The robustness to including only trade flows in the intensive margin, removing large countries and removing large sectors are shown in Table A.1, Table A.2 and Table A.3, respectively. Overall, the findings from this section regarding the influence of sectoral carbon leakage risk on the link between the allowance price and imports are quite robust to different datasets. At least as long as the years 2020-2022 are included in the data. In all robustness tests, the sign of the coefficients is very stable, and the magnitude only changes by small amounts.

## 4.3 Discussion

The previous two sections presented the results of this study. However, they did not delve too deeply into what these results mean. This section will describe what can be learned from the results and what limitations have to be kept in mind, thereby building on the discussion on identification, endogeneity and bias presented in section 3.2.

Up until now when discussing the results I have said that relative environmental policy stringency, or the allowance price, is *associated with* an increase in imports and an increase in exports. I have done this on purpose, and not said that relative environmental policy stringency *causes* higher imports and lower exports. That is because I think the potential for omitted variable bias, as discussed in section 3.2, is too high to realistically claim a causal effect of rEPS on imports. To reiterate, omitted variables would be any variables that correlate with the independent variable, the relative environmental stringency measure, and that also influence the dependent variable: imports. Some examples given in section 3.2 are energy prices, rising labour costs and a general de-industrialization trend in the EU. Such factors could all have caused an increase in imports and a decrease in exports, similar to how the EU ETS could influence imports. Because these variables are not included in the analysis and because I did not use a different way to control for the general time trend of increasing imports towards the EU, I have no way of causally attributing the effect I find to the EU ETS specifically. Therefore, the answer to the main research question, "Does the European Union emission trading system cause carbon leakage?", has to be "maybe". Nevertheless, the results still provide insight into the current state of competitiveness in European industry, and the research highlights the methodological challenges of studying carbon leakage through changes in imports.

First, although it is not possible to be sure if it is the EU ETS that caused the effect on trade flows, there is very clear evidence that there was a strong increase in imports and a decrease in exports in line with the allowance price increase. From 2015 to 2022, the allowance price increased from a low of around 5 euros to a high of 68 euros, in real terms. My results show that, with an estimated coefficient of 0.178, this 63 euro EU allowance price increase is associated with an increase in imports to and a decrease in exports from the EU of around 11% for the manufacturing and mining & quarrying sectors, keeping other factors fixed. That is while controlling for sector-specific worldwide trends and shocks. We do not know whether it is the EU allowance price that *caused* the changes in trade flows, but the results very clearly show that this change in trade flows did happen. Furthermore, the results from the regressions with the sectoral leakage risk dummies clearly indicate that the change in trade flows is larger for sectors on the official carbon leakage list, i.e. sectors that have high emission and trade intensity. This might be an indication that the EU ETS is causing carbon leakage, but it might also be that the change in trade flows is larger for these sectors for other reasons. If it is the EU ETS that causes the changes in trade flows for these sectors it would mean that the more generous free allocation for these sectors is not enough to prevent carbon leakage. Furthermore, the other results regarding the sectoral leakage risk groups indicate that it is unlikely that the sharp leakage list thresholds have caused higher carbon leakage risk for sectors just below the leakage list. In fact, the results show that for these sectors, the magnitude of the link between relative environmental stringency and imports was actually the smallest. The association between rEPS and imports is even larger for the "low risk" reference sectors with the lowest CL indicators than it is for the sectors just below the leakage list. Therefore, the results show that it is unlikely that the EU ETS free allocation rules have had large negative effects on sectors just below the leakage list. If the EU ETS had had negative effects on these sectors, they would have been outweighed by other sectoral factors that influenced changes in trade flows to and from the EU. The results regarding the lowest-risk sectors provide some interesting insight into the presence of omitted variable bias. The regression with both leakage risk group dummies, below leakage list and leakage list, using a CL indicator cutoff of 0.05, resulted in a coefficient of 0.1795 for the reference "low risk" sectors, Table 4.4. This means that even for the low-risk sectors with hardly any emission and trade intensity, there is a correlation between relative environmental policy stringency and imports. This result is an indication that my results are indeed affected by omitted variable bias, as hypothesised in section 3.2, because it seems highly unlikely that the EU ETS would have such a significant effect on low-risk sectors. These sectors, with a CL indicator below 0.05, have a low emission intensity as well as low trade intensity, and they should, therefore, not be affected by the EU ETS.

So, my methodology does not allow me to realistically claim a causal effect of the EU ETS on imports because of omitted variable bias, for which I also find some evidence in my results. However, it is important to keep in mind that it does not necessarily mean that carbon leakage is not happening due to the EU ETS. It is still likely that carbon leakage occurred because of the increased allowance price and stricter free allocation rules, as also supported by the findings of De Beule et al. (2022b). From my results, it seems unlikely that the sharp thresholds for the carbon leakage list caused carbon leakage to sectors just below these thresholds. In fact, I found that changes in imports were largest for sectors on the carbon leakage list. Therefore, if carbon leakage occurred it seems likely to have been in these sectors on the official carbon leakage list despite these sectors receiving more free allocation. These suggestions will have to be verified by future research. However, it can be helpful to discuss how carbon leakage could be occurring for sectors on the official carbon leakage list, even though these sectors receive more free allocation.

Therefore, I will now provide two hypotheses for how carbon leakage might be occurring in the sectors on the official carbon leakage list. These hypotheses will aid in formulating recommendations for future research. First, it could be that the **benchmarking** method that is used by the European Commission to distribute free allowances *within* a sector has a too large negative effect on some firms within a sector. As explained in section 2.4, firms receive up to 100% of the allowances they need based on a benchmark of the 10% most emission-efficient firms within a sector. Therefore, less efficient firms are disproportionally affected by price increases in the EU ETS, which might cause leakage within sectors on the official carbon leakage list. The second hypothesis is based on the idea that relocation or foreign direct investment (FDI) is a conscious decision by firm management and not just the consequence of some increase in allowance price. Importantly, the decisions in this case are based on **expectations** on what the future stringency of the EU ETS will be, instead of the state of the EU ETS at the current moment. Therefore, even though free allocation to firms on the official carbon leakage list is generous now, these firms might anticipate future decreases in the level of free allocation and opt for (partial) relocation of their production facilities. If these expectations play a large role it does not matter that free allocation is generous right now and firms might still relocate, causing carbon leakage. My results do not allow me to draw conclusions about these hypotheses. However, future research can take these issues into account.

My results and the discussion presented in this section indicate that more research is needed to answer the main research question of this thesis: Does the EU ETS cause carbon leakage? In section 2.5 in the literature review, it was shown that existing measures of environmental stringency used by other authors have the potential to bias the results against finding carbon leakage. For this reason, I used a novel measure of environmental stringency based on the allowance price. However, this measure does not allow the use of country-year fixed effects, which increases the potential for omitted variable bias. Therefore, the results presented in this thesis do not allow me to claim with certainty that the EU ETS caused carbon leakage. So, the choice of a method to study carbon leakage due to the EU ETS is by no means trivial, but this study has provided important insight into the potential methodological pitfalls. The next chapter will use these insights to provide recommendations for future research on carbon leakage. Subsequently, it will describe the implications of this study for policymakers in the European Commission.

# Chapter 5

# Methodological Recommendations and Implications for Policymakers

The previous chapter presents the results of this study and discusses what these results mean. In the discussion in section 4.3, it was explained that the results from the study can not be used to claim that the EU ETS has caused carbon leakage. That means that there is still a gap in the literature. There is still limited research that studies carbon leakage due to the EU ETS in recent years when the price increased and free allocation was reduced. Furthermore, there is no recent study that uses an environmental stringency measure based on the allowance price, that can be used to identify a causal effect of the EU ETS on trade flows. In section 2.5, it was explained that many older existing studies exhibit a chance of aggregation bias. Therefore, this chapter will start by providing a methodological recommendation on how these methods can be adapted to reduce aggregation bias and identify a causal effect of the EU ETS on trade flows, in section 5.1. This study also provided some valuable insight regarding the design of the EU ETS. Combined with the results, these will be used to provide recommendations to the European Commission, in section 5.2. Finally, section 5.3 will provide some recommendations to policymakers designing prospective ETSs.

## 5.1 Methodological Recommendations

The results from this study clearly show that for the manufacturing and mining & quarrying sectors, there has been an increase in imports to the EU and a decrease in exports from the EU. However, due to potential omitted variable bias, the effect cannot be attributed solely to the EU ETS with certainty. Therefore, the question of whether the EU ETS caused carbon leakage, and thus the changes in trade flows that were seen in my results, is still open. The potential omitted variable bias occurs due to the use of a novel measure of environmental stringency. One might wonder whether it is not better to take a step back and use a measure based on EU ETS costs, as other authors do, even though there might be aggregation bias in this case. This section will shortly discuss how aggregation bias can be reduced in a different way than done in this study, while also accounting for omitted variable bias. Therefore, carbon leakage due to the EU ETS can still be studied by regression analysis of trade flows.

Would it be better to use an environmental policy stringency measure based on sector-specific EU ETS costs, as used by Naegele and Zaklan (2019) and other authors? That would reduce the potential for omitted variable bias because it allows for including country-year fixed effects. However, one would need to deal with the issue of aggregation bias. To reiterate, aggregation bias might bias the results against finding carbon leakage. It occurs because sectors comprise a heterogeneous mix of individual firms with different emission intensities. When an emission-intensive firm relocates or loses market share, the average emission intensity of the sector decreases. At the same time, imports rise and exports fall. Therefore, the lower average emission intensity is associated with higher imports and lower exports, which is the exact opposite of what would be expected if carbon leakage occurs. It is difficult to determine a prior how large this aggregation bias effect is and how much the results will be affected. Because of aggregation bias I would not recommend just copying the methodology from Naegele and Zaklan (2019). However there is another way of dealing with aggregation bias than using a completely different measure of environmental stringency. Levinson and Taylor (2008) control for aggregation bias by using the instrumental variables (IV) method. An instrumental variable is chosen such that it does correlate with the explanatory variable, the relative environmental policy stringency, but not with any variables in the error term. Using this IV method, aggregation bias can be eliminated, and the effect of the EU ETS on trade flows can be estimated more reliably. Therefore, I would recommend other researchers to use an environmental stringency measure based on EU ETS costs and including country-year fixed effects plus instrumental variables. With such a method, there is less chance of the results being affected by omitted variable bias while at the same time controlling for aggregation bias.

## 5.2 Policy Recommendations for the European Commission

The results from this study have shown that there have been large changes in trade flows from 2013-2022 for manufacturing and mining & quarrying sectors. The results further show that these changes in trade flows are larger for emission- and trade-intensive sectors on the official carbon leakage list. However, two main things are not known after these results. First, what the role of the EU ETS is in these changes in trade flows. And second, how the results differ for the sectors, or even firms, within the groups of sectors. Without this information, the European Commission (EC) cannot make an informed decision on how to adapt the EU ETS. If the EU ETS played a limited role in the found competitiveness effects, the EC needs to consider other factors that influence the competitiveness of firms. This section will provide recommendations for the EC on how to adapt the EU ETS and it will point out some elements the EC needs to keep in mind regarding the competitiveness of European industry. First subsection 5.2.1 will describe the difficult situation the EU finds itself in currently. Second, subsection 5.2.2 will describe in two steps how the EC can improve the EU ETS. Finally, subsection 5.2.3 will describe why the EC should have a long-term vision for European industry and what factors to consider in such a vision.

### 5.2.1 The current situation

To understand what the EC can do to adapt the EU ETS and improve the competitiveness of European industry, it is crucial to understand the context. The results from this study have shown that there has been a large increase in imports and a large decrease in exports of manufacturing and mining & quarrying products. These findings signal negative competitiveness effects within these industries. Firms either invest in new production facilities outside of Europe and/or they lose market share to their foreign competitors. These findings are also reflected in public discourse, with news agencies and policy analysis platforms speaking of the deindustrialisation of Europe (Born et al., 2022; Grömling et al., 2023; Karnitschnig, 2023). There are many factors that contributed to this deindustrialization trend, but these are not all relevant to this study. With regard to this study, there are four main elements that describe the situation the EU finds itself in:

- Increasing geopolitical tensions
- Strong industrial policies by competitors
- High energy prices
- Planned reform of the EU ETS

First, in recent years **geopolitical tensions** have increased. One of the main factors in these tensions is the relationship with China. In 2019, the EC published "EU-China - A strategic outlook", in which China was described as an "economic competitor in the pursuit of technological leadership, and a systemic rival promoting alternative models of governance." (European Commission, 2019c). China is seen as a large economic rival and there is a fear of European companies being outcompeted by Chinese. Apart from China, the once very stable and friendly relationship with the US is no longer a given, with the US increasingly using protectionist measures. Especially given the possibility of the election of Donald Trump in 2024. Finally, the Russian of invasion of Ukraine in 2022 also had a large impact on the EU. It suddenly became clear how much the EU was dependent on Russian gas and oil and how vulnerable the EU was if these supplies were cut off. These factors all contribute to making strategic autonomy of the EU increasingly important.

Related to the geopolitical tensions are the **strong industrial policies** by Europe's main trading partners and competitors, China and the US. China has for a long time supported its industry with subsidies (Lindner et al., 2023). In 2019, these subsidies totalled 1.73% of Chinese GDP, which is more than three times as much as Germany, France or the US (DiPippo et al., 2022). That is also why recently, the EC instigated an import tariff on Chinese EVs because of "unfair subsidisation" of Chinese car manufacturers by the Chinese government (European Commission, 2024c). The other big competitor of the EU, the US, recently passed the Inflation Reduction Act (IRA). The IRA provides financial support for US industries producing clean technologies. The IRA poses a threat to European industry because it provides much larger financial support than the EU's Green Deal does (Lindner et al., 2023). Another advantage of the IRA over the EU's Green Deal is that it works through the tax system instead of through grants, which makes it a much simpler and more predictable system (Lindner et al., 2023).

Another factor that is detrimental to the competitiveness of European energy-intensive industry is the **high price of energy**. Following the Russian invasion of Ukraine in 2022, the price of gas and electricity in the EU increased massively (European Council, 2024). Even though gas and electricity prices decreased in 2023, they stabilised at levels around two times higher than the prices for industry in the US (Lindner et al., 2023). These high prices are partly caused by limited availability of fossil fuels within the EU and partly because of the higher costs for fossil fuel electricity due to the EU ETS. Even after the transition to renewable energy forms prices in the EU are expected to remain higher. This is the case because the EU has low wind and solar power potential due to limited space and less solar radiation compared to many other countries, respectively. (Verpoort et al., 2024).

Finally, a **reform of the EU ETS** has been set in motion with the introduction of the Carbon Border Adjustment Mechanism (CBAM), which the EC started rolling out in 2023. The CBAM is essentially an import carbon tax. Importers have to pay for the greenhouse gas emissions embodied in their products. At the EU border, they have to pay the same amount for their emissions as EU-based producers would have if they produced the same product in the EU. With the CBAM, the EU aims to level the competitive playing field and prevent carbon leakage. The CBAM takes over the function of free allocation and is set to replace free allocation by 2034 completely. The goal of the CBAM is to incentivise firms to further reduce emissions and, at the same time, increase EU ETS revenues. However, the CBAM faces opposition from some sectors. The European Round Table for Industry (ERT) criticizes the current plans for the CBAM because of loopholes that allow importers to not pay the true cost for their emissions and because the CBAM does not protect exporting European firms (European Round Table for Industry (ERT), 2024).

The first three elements described above do not paint a very positive picture for the future of industry in the EU. However, the EC should keep in mind that there are many factors that influence the investment decisions by firms. The EU has advantages over its competitors, such as well-developed infrastructure, access to robust energy infrastructure, a well-educated workforce and low risk for capital-intensive investment due to political stability (PwC, 2024). However, the EC needs to make sure it maintains these advantages while limiting the negative effects if it wants to keep its energy-intensive industry. The next sections will provide suggestions to the EC on how these goals can be achieved. First, I will provide suggestions on how to adapt the EU ETS, and then I will describe things the EC needs to reflect on regarding the competitiveness of its industry.

### 5.2.2 Adapting the EU ETS

This section will provide the EC with suggestions on how to adapt the EU ETS. This study has shown that there was a clear increase in imports and a decrease in exports from the EU in manufacturing and mining & quarrying industries in recent years. De Beule et al. (2022b) provided evidence that the EU ETS has caused some carbon leakage, but their results do not indicate the total scale of the impact of the EU ETS on competitiveness. Therefore, the EC first needs to find out what the influence of the EU ETS is on firm competitiveness. The second step two would be to use these findings to change the EU ETS framework. This subsection will now describe these two steps in more detail.

#### 5.2.2.1 Step 1: Find out what the Influence of the EU ETS is on Firm Competitiveness

First, the EC needs to find out what the influence of the EU ETS is on the competitiveness of firms and, thus, whether the EU ETS caused carbon leakage. It would be possible to follow the recommendation in section 5.1 and use regression analysis on panel data with the instrumental variables approach. This is likely one of the fastest and least resource-intensive methods for finding out whether the EU ETS caused carbon leakage. Another benefit is that this method results in a relation between the allowance price and changes in imports. Therefore, it could be used to predict future competitiveness effects based on expectations of the allowance price. The main downside of this method is that the EC would likely need data that is usually only available for a high level of aggregation, where many sub-sectors are combined into a smaller number of overarching sectors. Furthermore, such a method would only give insight into the influence of the EU ETS and not of other factors that influence firm decisions. Therefore, the EC could consider using a different method to find out the influence of the EU ETS on firm investment decisions to obtain more detailed insight. The EC can leverage its power and resources to use different methods than a researcher could, thereby increasing the level of detail in their results.

A possible method for the EC could be to survey member states and firms. Such a survey could inquire about past instances of firms investing in new production facilities outside the EU. Apart from learning about past instances of leakage, a survey could also be used to learn about the relative importance of factors that influence firm investment decisions. It could, for example, be used to ask firms about the importance of factors such as energy, capital, land and labour costs, availability of raw materials, corporate taxation, tariffs, labour regulation and, of course, the EU ETS. Using such a method, the EU needs to be aware of the possibility of strategic behaviour by firms. If you just ask firms whether the EU ETS is harmful to them, they will answer that it is very harmful and that the EC should make the EU ETS less strict. Therefore, such a method should be carefully chosen to limit the possibility of strategic behaviour by firms and member states. This could, for example, be done by asking firms to *rank* the relative importance of factors. Using such a method, firms are incentivised to give the factors that are most important to them the highest importance. Another way to ensure a sound methodology would be to use a method similar to Martin et al. (2014). They used structured telephone interviews to assign European firms a carbon leakage vulnerability score. They interviewed 400 managers of EU ETS-covered firms and asked them about the likelihood of their firm relocating or closing down in response to the EU ETS. They based their method on a survey interview method pioneered by Bloom and Reenen (2007). This method is specifically developed to reduce the potential for known types of bias in conventional surveys. In the end, the choice of the best methodology will depend on the EC's resources. Ideally, the EC would use a combination of different methods to strike a balance between obtaining results that are free from bias and, at the same time, having a high level of detail.

Regardless of the method the EC chooses, there are three possible scenarios regarding the influence of the EU ETS on the competitiveness of European firms:

1. The EU ETS has a large negative impact on competitiveness

2. The EU ETS has a negligible impact on competitiveness
3. The EU ETS has a positive impact on competitiveness

In reality, not one scenario applies to all sectors. Some sectors will most likely experience negative effects, whereas others might experience no negative effects or even positive effects. Therefore, how the EC can be adapted will also differ per sector. The next section will provide recommendations to the EC per scenario.

#### 5.2.2.2 Step 2: Adapting the EU ETS

In this section, I will provide recommendations to the EC for each of the scenarios described in the previous section. Revisions of the EU ETS framework will ultimately include a combination of these different recommendations because different sectors will be in different scenarios.

**Scenario 1. The EU ETS has a large negative impact on competitiveness:**

In this scenario, the costs due to the EU ETS are large enough to have large negative effects on a sector. If nothing is done, firms within this sector will close down facilities in Europe and gradually relocate elsewhere. The EC can consider the following questions when deciding if and how the EU ETS should be adapted:

- Is the sector of crucial importance to the strategic autonomy of the EU?
- Is it viable to keep the sector in the long-term?
- How can extra support for the sector be realised?

First, the EC should think about the **importance of the sector to the strategic autonomy of the EU**. As described in subsection 5.2.1, the EU finds itself in a time in which geopolitical tensions have increased. There will be products the EU wants to produce itself so that it is not reliant on trading partners in difficult times. However, there will also be products that are less important from a strategic autonomy point of view. Products that are produced in more than one country, for example, are less likely to lead to supply problems. Another factor that comes into play here is the size of the sector. Is it necessary for the sector to remain the size it currently is, or is it fine if the sector shrinks?

Second, the EC needs to think about the **viability of keeping the sector in the long term**. As explained in subsection 5.2.1, it is likely that electricity prices in Europe will remain higher than in other countries that have better renewable energy potential. Countries such as Australia, South Africa, the US, Brazil and Chile have much higher renewable energy potential than Europe (Verpoort et al., 2024). Verpoort et al. (2024) estimate that relocating the production of energy-intensive products such as steel, urea, and ethylene from Europe to these renewable-rich countries could lead to cost savings between 18% and 38%. Such cost differences could make it impossible for European companies to compete with firms from these countries without subsidies. If a firm needs ongoing subsidies to survive and remain competitive, it might be better for the EC to let the sector relocate away from Europe and search for an alternative solution to secure the strategic autonomy of the EU.

Finally, if the EC deems a sector crucially important and viable in the long term, it needs to determine **how extra support for the sector can be realised**. The EC can reduce the sector's costs due to the EU ETS by increasing the amount of free allocation to that sector or by increasing the total supply of allowances, thereby decreasing the EU allowance price. If the EC wants to provide benefits to only one sector, it is better to tweak the amount of free allocation for that sector specifically than to adjust the total supply of allowances. Alternatively the EC could provide benefits to the sector outside of the EU ETS. It could consider subsidizing the sector to help the transition towards a cleaner production process.

**Scenario 2: The EU ETS has a negligible impact on competitiveness**

In this scenario, the costs due to the EU ETS are not large enough for a sector to experience serious competitiveness effects. In this case, the EC can try to adapt the EU ETS to maximize benefits. It can consider the following questions:

- When do negative competitiveness effects occur?
- Is it possible to decrease the cap and increase the price?
- How to use increased revenue?

First, if possible, the EC can try to determine **when negative competitiveness effects occur** for a sector. If the EC is aware of the factors that influence the impact of the EU ETS on competitiveness, it can use this knowledge to adapt the policy. It would be ideal if the EC could find a level of cost at which the influence of the EU ETS becomes large enough to cause competitiveness effects. In that case, the EC can increase the price to those levels. Of course, there are many more factors that come into play here, most notably the sectoral carbon leakage risk factors described in section 2.3.

Second, the EC should consider whether it is possible to further **decrease the cap of total allowances, thereby increasing the price**. If competitiveness effects are negligible, it might be safe to do so. Doing that would increase revenues from the EU ETS and incentivise firms to further reduce their emissions. However, too large increases in price may lead to negative competitiveness effects. A downside of adjusting the cap is that it applies to all sectors equally.

If the EC decides to decrease the cap and increase the price, there will be an increase in revenues from the EU ETS. **How to use these revenues** is up to the EC. Currently, revenue from the EU ETS is mostly distributed to Member States to support investments in renewable energy and low-carbon technologies (green investment). The rest of the revenue is allocated to the EU's Innovation Fund and Modernisation Fund (European Commission, 2024f). As explained in subsection 5.2.1, Europe's funding of industry is small compared to China and the US. Any extra revenue to invest in clean technologies would therefore be helpful to bridge the competitiveness gap.

**Scenario 3: The EU ETS has a positive impact on competitiveness** In this third scenario the EU ETS has a positive impact on the competitiveness of firms within a sector. This idea aligns with the Porter hypothesis as described in section 2.1. The idea behind the Porter hypothesis is that environmental policies will force firms to innovate in more environmentally friendly and efficient technology, increasing their productivity, offsetting any negative effects and getting ahead of the competition. There has been no evidence yet for such a strong effect in the literature. However, the fact that the EU allowance price has increased a lot may also mean that potential positive effects of such a policy have become stronger. Therefore, it might be possible that there is a positive impact of the EU ETS on some sectors. If the EC finds evidence for such an effect, it may want to use these findings to try to stimulate a similar effect in other sectors. The EC can consider the following questions:

- What factors differentiate these sectors from other sectors with negligible or negative effects?
- Is it possible to increase revenues and further promote green investment?

First, the EC will want to find out **what differentiates the sectors with positive effects from other sectors**. If the EC finds evidence of such a positive effect, it can further investigate the sector in question. The EC should try to determine whether the effect is caused by a fixed sector-specific factor or by other factors that can be influenced by EC policies. If possible, the EC can try to replicate a similar effect in other sectors.

Second, the EC can consider whether **it is possible to increase revenues and further improve green investment**. This question is similar to the second scenario. If the EU ETS has positive effects on competitiveness, it is even more likely that it is safe to increase revenues. Letting this revenue flow back to investment in clean technologies and renewable energy could further increase the EU ETS's positive effects.

### 5.2.3 A Long-term Vision for European Industry

From the results of this study and from the description of the current situation of the EU in subsection 5.2.1 it should be clear that there are negative competitiveness effects for European energy intensive industry. Regardless of whether these effects are caused by the EU ETS, if nothing is done it is likely that these effects will continue. As also discussed in scenario one above it may be the case that this is fine for some sectors, but there will also be sectors that are of vital importance to the EU. However, with the shift to renewable energy and clean technologies, the European industry in 30 years will look a lot different from now. Therefore, if the EC wants to provide targeted policies, as proposed in the scenarios above, it needs a **long-term vision for European Industry**. When thinking about such a vision, the EC should reflect on several issues. I will now present some of the issues that are most relevant to the rest of the discussion in this study, as a final recommendation to the EC:

- Find the balance between strategic autonomy, economic efficiency and climate change mitigation
- See Europe as one and use the different resources of different countries efficiently
- Remember that firm investment decisions are dependent on many factors
- Firms value certainty in their investment decisions

- Involve relevant actors in the decision making process
- Limit the complexity of regulations

First of all, the EC needs to strike a **balance between strategic autonomy, economic efficiency and climate change mitigation**. More strategic autonomy may lead to lower economic efficiency because the EU may not be suitable for the production of certain energy intensive products due to limited renewable energy potential. Similarly, striving for more climate change mitigation may cause carbon leakage, thereby harming strategic autonomy and possibly economic efficiency. The EC needs to balance these three elements such that it ideally maintains an economy that is autonomous enough, while at the same time being economically efficient and competitive and also at the forefront of fighting climate change.

Second, the EC should be aware of the different resources that different countries within Europe bring. It can help if **Europe is seen as one entity that shares resources among countries**. Southern Europe has a much higher renewable energy potential than northwestern Europe due to an abundance of solar radiation. Spain, for example, has a 50% greater solar power potential than the Netherlands and Germany (Reuters, 2023). If Europe is seen as one entity, the European economy can be much more efficient by moving energy-intensive industry to places with abundant cheap renewable energy.

Third, it is important to keep in mind that **firm investment decisions are dependent on many factors**. Europe does not need to have the cheapest electricity or the lowest carbon price if it makes up for these factors in other aspects, such as the education level of the workforce, well-developed infrastructure and high stability. Improving one of the factors that influence competitiveness by a little should not come at the expense of degrading other factors.

Fourth, regardless of what the EC decides, it should never make a 180-degree switch in the direction of regulations because **firms highly value certainty in their investment decisions**. In basic materials and energy industries, it can take 20-30 years for new investment projects to generate a return (Galonske et al., 2004). While this period may be shorter for other industries, building an entirely new manufacturing plant will always be a long-term investment decision. When making such a decision, firms weigh different factors such as energy, capital, land and labour costs, availability of raw materials, corporate taxation, tariffs, labour regulation and, of course, the EU ETS. Uncertainty in one of these factors can significantly increase the risk of an investment. Therefore, the EC should do its best to limit the uncertainty of these factors in the EU to increase the chance that firms stay in the EU and place their large investments there.

Fifth, the EC should **involve relevant actors in the decision-making process** when deciding on new regulations. Involving these actors will reveal the value conflicts that are at play. Firms and their employees will argue that carbon leakage should, at all costs, be prevented. Similarly, actors who are worried about the dependence of the EU on China will also want to keep as much industry in the EU as possible. On the other hand, green political parties and environmental agencies will likely have fewer objections against the most emission-intensive firms leaving the EU. They will argue that it is better to make the

EU ETS more strict to generate more revenue, which can be used to promote emission-reducing innovation. To ensure the EC makes the decision that does right to the values of the different actors, it needs to involve these actors in the process. The EC usually does this by engaging in stakeholder consultations, as they also did for the previous changes to the EU ETS framework; see, for example, European Commission (2018c).

Finally, when trying to navigate all the issues presented above it becomes attractive to add more regulations, specific rules for specific sectors and exceptions to rules. However, the EC should try to **limit the complexity of regulations**. European regulations, such as the European Green Deal are often criticised for being overly complex (Lindner et al., 2023). The EC can look to other countries to gain inspiration on how to achieve more, with less complexity. The US's inflation reduction act for example, by working through the tax code, is applauded for its simplicity and predictability (Lindner et al., 2023).

## 5.3 Recommendations for Other ETS Designs

Findings regarding the EU ETS can be used to inform the design of other (prospective) ETSs. Currently, there are over 20 ETSs under consideration worldwide (World bank, 2023). The policymakers who have to design these ETSs will likely look towards the EU ETS for inspiration, as it is the first and most well-established ETS worldwide. The results from this study do not provide a clear answer on whether the EU ETS caused carbon leakage. However, the findings from this study may still provide some insight for policymakers in other countries. First of all, the results indicate that the sharp thresholds that were used to determine the official carbon leakage list did not have large negative consequences on firms just below the leakage list. Moreover, as explained in section 2.4, the EC decreased the number of sectors on the official leakage list from 175 to 63 from phase 3 to phase 4. Most of the sectors on the list for phase 3 did not have any significant risk of carbon leakage. Designers of prospective ETSs, therefore, do not have to be as careful as the EC when starting their ETS systems. They can generate more revenue by assigning free allocation to fewer sectors, and they do not have to be too worried that sharp thresholds will negatively impact sectors just below the threshold. However, these ETS designers have to be aware that the results from this study should be verified and that more research is necessary to determine whether the EU ETS caused significant carbon leakage in recent years. Another recommendation for future ETS designs is to watch how the implementation of the CBAM goes in the EU ETS. The CBAM is a controversial measure because it can be seen as a disguised trade barrier and because it puts a disproportionate strain on developing countries that depend on exports of emission-intensive products to the EU (Eicke et al., 2021). However, the CBAM does lead to a lot more revenues for the EU ETS for two reasons. First, the CBAM will directly generate revenue because it taxes imports of carbon-intensive products. Second, the CBAM will replace the free allocation system, which will ensure more revenues from the EU ETS-covered firms. Therefore, if the EC successfully implements the CBAM and it works well, other countries may follow the example and implement a CBAM directly from the start without the need to also use free allocation. These are the main recommendations that can be given based on the results of this study. Other recommendations will have to follow from future research on carbon leakage due to the EU ETS.

# Chapter 6

# Conclusion

This thesis aimed to answer the question, **"Does the European Union Emissions Trading System (EU ETS) cause carbon leakage?"** This topic is relevant today because, in recent years, the EU allowance price has increased significantly, and the EU ETS has become more stringent by releasing fewer allowances for free. The limited amount of recent empirical evidence from the literature suggests that the EU ETS has indeed caused carbon leakage in recent years. However, these existing studies include data up until 2020, do not take the EU allowance price into account explicitly and do not provide evidence on the total scale of carbon leakage. For these reasons, this study employed an empirical analysis in which these elements were taken into account. Furthermore, a novel environmental policy stringency measure was used to reduce the potential for aggregation bias.

The results from this study indicate that answering the research question is not straightforward. The empirical findings demonstrated a correlation between increased imports and decreased exports with the rise in allowance prices. However, claiming a definitive causal relationship between the EU ETS and carbon leakage is not feasible due to potential omitted variable bias. This bias emerged as a result of improvements over previous research methodologies. To eliminate the risk of aggregation bias, the novel environmental policy stringency measure was designed to be non-sector-specific, reflecting the allowance price for all sectors. Consequently, it became impossible to control for the general de-industrialisation trend in the European Union and isolate the effect of the EU ETS on trade flows. As a result, the research question cannot be answered with absolute certainty at the end of this thesis. Nevertheless, the results still provide other valuable insights into the competitiveness of European firms.

The empirical analysis conducted as part of this thesis demonstrated a significant association between the EU ETS allowance price and changes in trade flows. This result shows that the European manufacturing and mining & quarrying sectors have lost competitiveness compared to their counterparts outside the EU. How much of this effect is due to the EU ETS and how much to other factors cannot yet be concluded. The association between the allowance price and trade flows was particularly notable for sectors that are included on the official carbon leakage list. These sectors, which are characterized by high emission and trade intensity, showed larger changes in trade flows for the same changes in allowance price. This suggests that the competitiveness effects are largest for these sectors. Conversely, sectors that are just below the threshold for inclusion on the carbon leakage list did not exhibit significant negative impacts, indicating that the current sharp thresholds used for the official list have not had *large* negative effects on these firms.

In conclusion, while the current evidence does not definitively attribute carbon leakage to the EU ETS, the study provides valuable methodological insights. These insights contribute to the broader academic literature on the impact of environmental policies on competitiveness and carbon leakage. Future researchers can use these insights to inform their methodological choices and reduce bias in their results. Economists should aim to isolate the effect of the EU ETS on trade flows by reducing omitted variable bias while at the same time reducing the potential for aggregation bias, which can be done by using an instrumental variables approach. Although the impact of the EU ETS requires further research, the results from this study clearly indicate that European industry is losing competitiveness. In the light of increasing geopolitical tensions and the resulting pull towards more strategic autonomy of the EU the degrading competitiveness of European industry is an important issue. The European Commission can adapt the EU ETS in two steps: First, by gaining more evidence on how large the influence of the EU ETS is on competitiveness, and second, by adapting the EU ETS based on these findings. Finally, the EC faces the challenge of having to develop a vision of what it wants the European industry to look like in the future. The EC needs to meet ambitious climate goals, while at the same time keeping the EU autonomous and competitive in a challenging geopolitical context.

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# Appendix A

# Additional Robustness Tests

This appendix shows the results of various robustness tests performed to assess the robustness of this study's findings.

**Trade flows in the intensive margin**
Robustness of the results to only keeping the combinations of importer, exporter and sector that have observations in each year. Thereby the results relate to the effects on trade flows in the intensive margin, i.e. changes from year to year instead of changes in terms of new trade flows.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| *Variables* | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1846*** | 0.2120*** | 0.1738*** | 0.1950*** |
| | (0.0061) | (0.0075) | (0.0059) | (0.0076) |
| *Interactions* | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | | -0.0696*** | | -0.0458*** |
| | | (0.0093) | | (0.0104) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | | | 0.0784*** | 0.0555*** |
| | | | (0.0110) | (0.0124) |
| $R^2$ | 0.9088 | 0.9088 | 0.9088 | 0.9088 |
| Observations | 2,955,360 (all columns) | | | |

*Clustered (exporter-importer-ISIC3) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table A.1**
Results of regression including interactions with sectoral leakage risk dummies. The dataset includes only observations for combinations of importer, exporter and sector that are observed in each year. Thereby looking at trade flows in the intensive margin, to test the robustness of the results. These regressions include the 100 largest countries, and all use a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold. All regressions include country-pair-sector and sector-year fixed effects

**5 largest countries removed**
Robustness of the results for both the baseline and sectoral leakage risk groups on a dataset with the five largest countries, in terms of total trade quantity, removed. These five countries are, in descending order, China, the United States, Australia, Russia and India.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| *Variables* | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1820*** | 0.2101*** | 0.1663*** | 0.1793*** |
| | (0.0059) | (0.0073) | (0.0056) | (0.0073) |
| *Interactions* | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | | -0.0707*** | | -0.0278*** |
| | | (0.0090) | | (0.0101) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | | | 0.1122*** | 0.0979*** |
| | | | (0.0109) | (0.0122) |
| $R^2$ | 0.8934 | 0.8934 | 0.8934 | 0.8934 |
| Observations | 3,890,298 (all columns) | | | |

*Clustered (exporter-importer-ISIC3) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table A.2**
Results of regression including interactions with sectoral leakage risk dummies. Trade flows involving the 5 largest countries were removed to show robustness. These regressions include the 100 - 5 largest countries, and all use a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold. All regressions include country-pair-sector and sector-year fixed effects

**Removing different amounts of large sectors** Robustness of the results to removing different numbers of largest sectors, in terms of total trade quantity.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| # of large sectors rem. | None | None | 5 | 5 | 10 | 10 | 20 | 20 |
| *Variables* | | | | | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.1780*** | 0.1795*** | 0.1717*** | 0.1791*** | 0.1685*** | 0.1801*** | 0.1715*** | 0.1856*** |
| | (0.0056) | (0.0068) | (0.0055) | (0.0069) | (0.0056) | (0.0070) | (0.0057) | (0.0072) |
| *Interactions* | | | | | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | | -0.0346*** | | -0.0382*** | | -0.0403*** | | -0.0392*** |
| | | (0.0096) | | (0.0095) | | (0.0095) | | (0.0097) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | | 0.0844*** | | 0.0708*** | | 0.0570*** | | 0.0621*** |
| | | (0.0115) | | (0.0116) | | (0.0117) | | (0.0126) |
| $R^2$ | 0.8985 | 0.8985 | 0.8973 | 0.8973 | 0.8967 | 0.8967 | 0.8937 | 0.8937 |
| Observations | 4,305,537 | 4,305,537 | 4,169,967 | 4,169,967 | 3,972,493 | 3,972,493 | 3,570,274 | 3,570,274 |

*Clustered (exporter-importer-ISIC3) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table A.3**
Results of regression including interactions with sectoral leakage risk dummies with different amounts of large sectors removed to show robustness. These regressions include the 100 largest countries, and all use a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold. All regressions include country-pair-sector and sector-year fixed effects

**Differing number of countries for sectoral leakage risk groups**
Robustness of the results for the sectoral leakage risk groups for different numbers of small countries removed from the dataset.

| Dependent Variable: | Logarithm of trade flow: $ln(y_{mxst})$ | | | | | |
|---|---|---|---|---|---|---|
| Number of countries: | 50 | 75 | 100 | 125 | 150 | all(228) |
| *Variables* | | | | | | |
| Policy stringency: $rEPS_{mxt}$ | 0.2453*** | 0.1834*** | 0.1795*** | 0.1828*** | 0.1867*** | 0.1807*** |
| | (0.0104) | (0.0077) | (0.0068) | (0.0064) | (0.0061) | (0.0059) |
| *Interactions* | | | | | | |
| Just below LL: $rEPS_{mxt} \times bLL_{st}$ | -0.0516*** | -0.0329*** | -0.0346*** | -0.0352*** | -0.0345*** | -0.0350*** |
| | (0.0146) | (0.0108) | (0.0096) | (0.0090) | (0.0085) | (0.0081) |
| Leakage list: $rEPS_{mxt} \times LL_{st}$ | 0.0937*** | 0.0905*** | 0.0844*** | 0.0823*** | 0.0843*** | 0.0749*** |
| | (0.0175) | (0.0130) | (0.0115) | (0.0108) | (0.0103) | (0.0099) |
| Observations | 1,683,060 | 3,162,327 | 4,305,537 | 5,119,973 | 5,852,907 | 6,627,471 |
| $R^2$ | 0.9106 | 0.9040 | 0.8985 | 0.8960 | 0.8934 | 0.8928 |

*Clustered (exporter-importer-ISIC3) standard-errors in parentheses*
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

**Table A.4**
Results of regression including interactions with sectoral leakage risk dummies with different numbers of small countries removed to test robustness. These regressions all use a CL indicator cutoff of 0.05 to determine sectors just below the leakage list threshold. All regressions include country-pair-sector and sector-year fixed effects

# Appendix B

# List of Sectors Included in the Regression Analysis

**Table B.1**
ISIC3 codes and descriptions of sectors included in the regression analysis

| ISIC3 code | Description |
|---|---|
| 1010 | Mining and agglomeration of hard coal |
| 1020 | Mining and agglomeration of lignite |
| 1030 | Extraction and agglomeration of peat |
| 1110 | Extraction of crude petroleum and natural gas |
| 1200 | Mining of uranium and thorium ores |
| 1310 | Mining of iron ores |
| 1410 | Quarrying of stone, sand and clay |
| 1421 | Mining of chemical and fertilizer minerals |
| 1422 | Extraction of salt |
| 1429 | Other mining and quarrying n.e.c. |
| 1511 | Production, processing and preserving of meat and meat products |
| 1512 | Processing and preserving of fish and fish products |
| 1513 | Processing and preserving of fruit and vegetables |
| 1514 | Manufacture of vegetable and animal oils and fats |
| 1520 | Manufacture of dairy products |
| 1531 | Manufacture of grain mill products |
| 1532 | Manufacture of starches and starch products |
| 1533 | Manufacture of prepared animal feeds |
| 1541 | Manufacture of bakery products |
| 1542 | Manufacture of sugar |
| 1543 | Manufacture of cocoa, chocolate and sugar confectionery |
| 1544 | Manufacture of macaroni, noodles, couscous and similar farinaceous products |
| 1549 | Manufacture of other food products n.e.c. |
| 1551 | Distilling, rectifying and blending of spirits |

Continued on next page

**Table B.1 – continued from previous page**

| ISIC3 code | Description |
|---|---|
| 1552 | Manufacture of wines |
| 1553 | Manufacture of malt liquors and malt |
| 1554 | Manufacture of soft drinks |
| 1600 | Manufacture of tobacco products |
| 1711 | Preparation and spinning of textile fibres |
| 1721 | Manufacture of made-up textile articles, except apparel |
| 1722 | Manufacture of carpets and rugs |
| 1729 | Manufacture of other textiles n.e.c. |
| 1730 | Manufacture of knitted and crocheted fabrics and articles |
| 1810 | Manufacture of wearing apparel, except fur apparel |
| 1820 | Dressing and dyeing of fur |
| 1911 | Tanning and dressing of leather |
| 1920 | Manufacture of footwear |
| 2010 | Sawmilling and planing of wood |
| 2021 | Manufacture of veneer sheets |
| 2022 | Manufacture of builders' carpentry and joinery |
| 2029 | Manufacture of other products of wood |
| 2101 | Manufacture of pulp, paper and paperboard |
| 2102 | Manufacture of corrugated paper and paperboard and of containers of paper and paperboard |
| 2109 | Manufacture of other articles of paper and paperboard |
| 2221 | Printing |
| 2310 | Manufacture of coke oven products |
| 2320 | Manufacture of refined petroleum products |
| 2330 | Processing of nuclear fuel |
| 2411 | Manufacture of basic chemicals, except fertilizers and nitrogen compounds |
| 2412 | Manufacture of fertilizers and nitrogen compounds |
| 2413 | Manufacture of plastics in primary forms and of synthetic rubber |
| 2421 | Manufacture of pesticides and other agro-chemical products |
| 2422 | Manufacture of paints, varnishes and similar coatings, printing ink and mastics |
| 2423 | Manufacture of pharmaceuticals, medicinal chemicals and botanical products |
| 2424 | Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations |
| 2429 | Manufacture of other chemical products n.e.c. |
| 2430 | Manufacture of man-made fibres |
| 2511 | Manufacture of rubber tyres and tubes |
| 2519 | Manufacture of other rubber products |
| 2520 | Manufacture of plastics products |
| 2610 | Manufacture of glass and glass products |

Continued on next page

**Table B.1 – continued from previous page**

| ISIC3 code | Description |
|---|---|
| 2691 | Manufacture of non-structural non-refractory ceramic ware |
| 2692 | Manufacture of refractory ceramic products |
| 2693 | Manufacture of structural non-refractory clay and ceramic products |
| 2694 | Manufacture of cement, lime and plaster |
| 2695 | Manufacture of articles of concrete, cement and plaster |
| 2699 | Manufacture of other non-metallic mineral products n.e.c. |
| 2710 | Manufacture of basic iron and steel |
| 2720 | Manufacture of basic precious and non-ferrous metals |
| 2811 | Manufacture of structural metal products |
| 2812 | Manufacture of tanks, reservoirs and containers of metal |
| 2813 | Manufacture of steam generators, except central heating hot water boilers |
| 2893 | Manufacture of cutlery, hand tools and general hardware |
| 2899 | Manufacture of other fabricated metal products n.e.c. |
| 2911 | Manufacture of engines and turbines, except aircraft, vehicle and cycle engines |
| 2912 | Manufacture of pumps, compressors, taps and valves |
| 2913 | Manufacture of bearings, gears, gearing and driving elements |
| 2914 | Manufacture of ovens, furnaces and furnace burners |
| 2915 | Manufacture of lifting and handling equipment |
| 2919 | Manufacture of other general purpose machinery |
| 2921 | Manufacture of agricultural and forestry machinery |
| 2922 | Manufacture of machine-tools |
| 2923 | Manufacture of machinery for metallurgy |
| 2924 | Manufacture of machinery for mining, quarrying and construction |
| 2925 | Manufacture of machinery for food, beverage and tobacco processing |
| 2926 | Manufacture of machinery for textile, apparel and leather production |
| 2927 | Manufacture of weapons and ammunition |
| 2929 | Manufacture of other special purpose machinery |
| 2930 | Manufacture of domestic appliances n.e.c. |
| 3000 | Manufacture of office, accounting and computing machinery |
| 3110 | Manufacture of electric motors, generators and transformers |
| 3120 | Manufacture of electricity distribution and control apparatus |
| 3130 | Manufacture of insulated wire and cable |
| 3150 | Manufacture of electric lamps and lighting equipment |
| 3190 | Manufacture of other electrical equipment n.e.c. |
| 3210 | Manufacture of electronic valves and tubes and other electronic components |
| 3220 | Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy |
| 3230 | Manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods |

Continued on next page

**Table B.1 – continued from previous page**

| ISIC3 code | Description |
|---|---|
| 3311 | Manufacture of medical and surgical equipment and orthopaedic appliances |
| 3312 | Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment |
| 3313 | Manufacture of industrial process control equipment |
| 3320 | Manufacture of optical instruments and photographic equipment |
| 3410 | Manufacture of motor vehicles |
| 3420 | Manufacture of bodies (coachwork) for motor vehicles |
| 3430 | Manufacture of parts and accessories for motor vehicles and their engines |
| 3511 | Building and repairing of ships |
| 3512 | Building and repairing of pleasure and sporting boats |
| 3520 | Manufacture of railway and tramway locomotives and rolling stock |
| 3530 | Manufacture of aircraft and spacecraft |
| 3591 | Manufacture of motorcycles |
| 3599 | Manufacture of other transport equipment n.e.c. |
| 3610 | Manufacture of furniture |
| 3692 | Manufacture of musical instruments |
| 3693 | Manufacture of sports goods |
| 3694 | Manufacture of games and toys |
| 3699 | Other manufacturing n.e.c. |