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The effect of carbon taxes on carbon leakage in EU ETS countries

Abstract

Carbon leakage is an important issue with regards to the effectiveness of climate policies, such as carbon taxation. Ex-ante literature predicts that stringent policies induce carbon leakage, whereas the ex-post literature finds no evidence for this. This paper investigates whether carbon taxes introduced in countries covered by the EU emission trading system (ETS) have caused carbon leakage. To measure carbon leakage, I compute net trade flows in embodied carbon and in added value using an OECD dataset and combine this with carbon pricing data from the World Bank. I find limited evidence that carbon taxes induced carbon leakage in the 30 countries included in my sample between 1995 and 2018.

Keywords: Carbon Tax, Carbon Leakage, EU ETS, Net trade flows

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1. Introduction

Climate change refers to a long term-shift in global weather patterns caused by human activities, such as burning fossil fuels and deforestation, which release large amounts of greenhouse gases into the atmosphere (Mikhaylov et al, 2020). Climate change is a significant problem because it poses significant risks to ecosystems, human health, and the global economy. It contributes to extreme weather events such as floods, droughts, hurricanes and wildfires, which have devastating impacts on people and the environment. Without urgent action to mitigate its effects, climate change will continue to cause severe damage to the planet's biodiversity and human well-being.

The Paris Climate Agreement, which was adopted in December 2015 by 196 parties to the United Nations Framework Convention on Climate Change (UNFCCC), was a landmark global agreement to combat climate change. The primary goal of the agreement is to limit the increase in the global average temperature to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees above pre-industrial levels (Schleussner et al., 2016). Since the adoption of the Paris Agreement, countries around the world have taken significant steps to reduce their greenhouse gas emissions and transition to a more sustainable, low-carbon economy.

The European Union has positioned itself as a global leader in combatting the climate crisis. EU leaders aspire to make Europe the first economy worldwide to become climate-neutral by 2050 (European Council, 2021). In order to achieve this goal, various environmental policies have been implemented at EU- and member level, such as the European Union's Emissions Trading System (EU ETS). The EU ETS, introduced in 2005, is a market-based cap-and-trade system that sets an absolute quantity limit on CO_2 emissions of 12,000 emitting facilities within the European Union (Ellerman & Joskow, 2008). The system has been adopted by the 27 EU member states plus Iceland, Liechtenstein, and Norway, and covers around 40 percent of the EU's total greenhouse gas emissions (European Commission, 2023). The main goals of the ETS are to reduce emissions by increasing energy efficiency and stimulating low carbon technological innovation.

Several countries within the EU ETS system have adopted additional climate policies, such as carbon taxation. The main reason for this is that member nations want to price carbon in sectors that are not included in the EU ETS. For example, Austria introduced its carbon tax in 2022 to cover the transportation, building, waste and agriculture sectors (ICAP, 2022). Furthermore, countries may introduce carbon taxes to fill the gap between their national emission reduction goals and those of the European Union. For example, the Netherlands has a relatively large energy-intensive industry, with polluters like Tata steel, Shell, Chemelot, and therefore requires more aggressive policies to realise the energy transition (Sleven, 2020).

A carbon tax sets a price on carbon by defining a tax rate on the carbon content of fossil fuels. It is different from the ETS in that the emission reduction outcome of a carbon tax is not pre-defined, but the carbon price is (World Bank, 2023). The following 18 EU ETS countries have introduced carbon taxation: Finland (1990), Poland (1990), Norway (1991), Sweden (1991), Denmark (1992), Slovenia (1996), Estonia (2000), Latvia (2004), Liechtenstein (2008) Iceland (2010), Ireland (2010), United Kingdom (2013), France (2014), Spain (2014), Portugal (2015), Luxembourg (2021), Netherlands (2021) and Austria (2022) (The World Bank, 2022).

When introducing a policy such as carbon taxation, it is always important to evaluate its effectiveness in achieving its goals. The literature finds mixed effects of carbon taxes, depending on whether it stimulates innovation (Porter's hypothesis), or leads to a relocation of production (Pollution haven hypothesis). In the case of Porter's hypothesis, carbon taxation may lead to reduced carbon emissions, improved energy and increased adoption of renewable/low carbon technologies (Porter & van der Linde, 1995). However, according to the pollution haven hypothesis, carbon taxes can lead to decreased competitiveness of domestic firms relative to foreign firms in unregulated regions, which may ultimately result in carbon leakage.

Carbon leakage is a term used to describe the phenomenon in which companies or industries move their operations, along with the associated greenhouse gas emissions, to regions with less stringent climate policies or weaker environmental regulations (European Commission, 2023). Carbon leakage means that the domestic climate mitigation policy is less effective and more costly in containing emission levels, which is a legitimate concern for policymakers (IEA, 2008). The main indicator of whether carbon leakage has occurred is a change in trade patterns. For a given level of domestic consumption of a carbon-intensive product, carbon leakage leads to a higher share of imports in total consumption of the home region (Naegele & Zaklan, 2019).

Although there is a broad empirical literature on the effect of trade on environment, the literature on the impact of environmental regulations on trade flows is relatively scarce, very heterogeneous and presents mixed results. One strand of literature using general equilibrium models forecast, ex-ante, that environmental regulations cause large changes in trade patterns, indicating carbon leakage. On the contrary, ex-post empirical research finds little evidence for carbon leakage caused by different types of environmental policies.

This paper aims to contribute to the literature by investigating whether carbon taxation in EU ETS countries affect a country's trade patterns, as this may indicate that carbon leakage has occurred. Therefore, the main research question of this paper is: **"What is the effect of carbon taxation on carbon leakage within EU ETS countries?"**

Using data from the World Bank and OECD, I adopt a fixed effects model to regress carbon taxation on net imports – measured in embodied carbon and in value added in EU ETS countries. My final sample includes 30 countries and covers the time period from 1995-2018. 14 of these countries had a carbon tax in place during the sample period.

This question is important to investigate because it has several practical applications for climate policymakers. Firstly, it helps policymakers to evaluate the effectiveness of the carbon tax, as a high carbon leakage indicates that the international climate goals are being reached slower than expected. Secondly, if I find that there is a high level of carbon leakage, then this will provide additional support for the upcoming EU Carbon Border Adjustment Mechanism (CBAM) regulation. This policy aims to combat carbon leakage by charging a price on the carbon emissions embodied in certain goods imported into the EU. This ensures that the carbon price of imports is equal to the domestic carbon price, such that EU ETS firms maintain their international competitiveness and are not incentivised to offshore their emission-intensive production activities (European Commission, 2023).

To the best of my knowledge, this is the first research investigating the effect of carbon taxes on carbon leakage within EU ETS countries. There are a handful of ex-post studies in the broader policy-induced carbon leakage field, but these investigate other climate policies (i.e. EU ETS/Kyoto protocol) and/or look at a different sample of countries. In recent years, the cost burden of environmental policies has increased due to the rising carbon tax rates. My paper is therefore valuable because the data captures these recent years, in contrast to the previous literature. Moreover, I use a relatively new dataset constructed by the OECD to analyse the carbon embodied trade flow patterns.

The remainder of this paper is structured as follows: Section 2 discusses the theoretical background and reviews the existing literature; Section 3 describes the methodology and data used; Section 4 presents the results and their robustness; and Section 5 concludes with a discussion and practical implications for policymakers.

2. Theoretical Background

Theory on Carbon Leakage

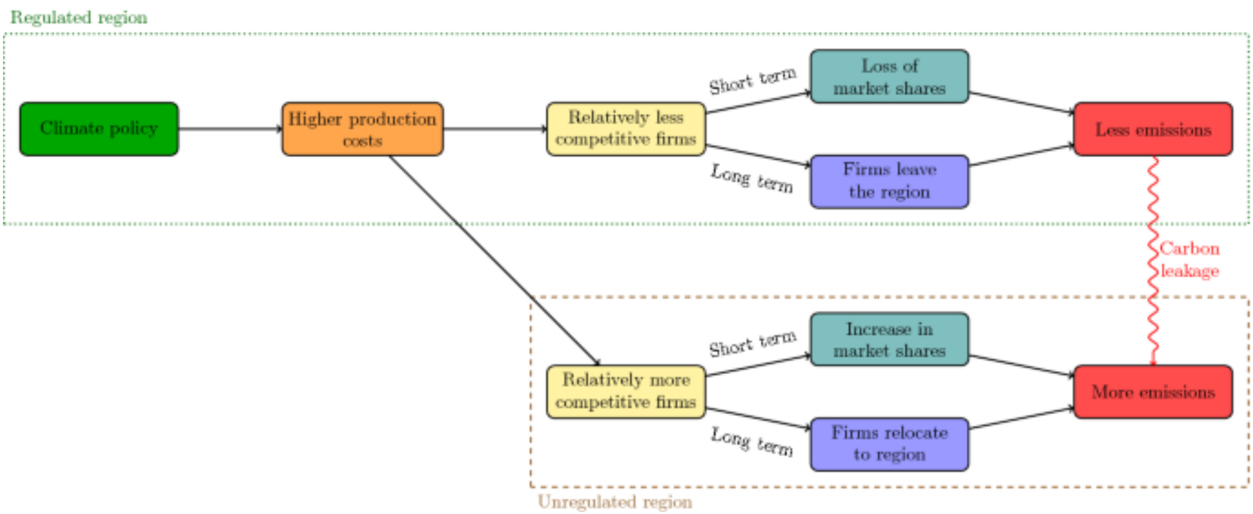
Carbon leakage is the displacement of carbon emissions from a region with stringent climate policies towards a region with less stringent climate policies (Naegele & Zaklan, 2019). According to Cameron & Baudry (2023), there are three channels through which environmental policy affect carbon leakage. Carbon leakage is most commonly understood through the competition channel (pollution haven hypothesis), which is the mechanism through which the regulated domestic firms lose their competitiveness against unregulated foreign firms (Grossman & Krueger, 1991). This may lead to a relocation of the domestic firms to avoid these compliance costs, or a loss in their relative market shares. Secondly, carbon leakage can also occur through the energy channel. Firms in the regulated region reduce their demand for fossil fuels, leading to price drops in international markets. This drop in price incentivizes firms in unregulated regions to increase their fossil fuel consumption, and hence their emissions (Cameron & Baudry, 2023). Lastly, the innovation channel (porter hypothesis), has the opposite effect to the other channels, by decreasing carbon leakage. According to this channel, more stringent environmental policies will lead to an increase in R&D and diffusion of carbon-reducing innovations, both domestically and abroad (Porter & van der Linde, 1995). In this paper, I will analyse carbon leakage through the combination of the three channels.

i) Competition Channel (Pollution Haven Hypothesis)

Carbon leakage through the competition channel occurs when one region introduces environmental policies on firms operating within its borders that are more stringent than in other regions. As a result, the domestic regulated producers face additional compliance costs, putting them at a competitive disadvantage compared to foreign unregulated producers who supply the same markets.

Under perfect competition, this loss of competitiveness among domestic producers can have two possible consequences. Firstly, in the short run, domestic producers may lose market shares to their foreign counterparts, who become more competitive as they do not have to bear the additional cost (Naegele & Zaklan, 2019). Hence, the foreign producers will increase their production, resulting in a rise in (carbon) emissions in the unregulated region. Secondly, in the long run, domestic producers may decide to relocate their production to countries with less stringent regulations to avoid the higher compliance costs. This is also known as the pollution haven hypothesis, which was first proposed by (Grossman & Krueger, 1991). Once again, (carbon) emissions will be displaced towards the unregulated region, indicating that carbon leakage has occurred. Figure 1 below visualizes how carbon leakage occurs through the competition channel.

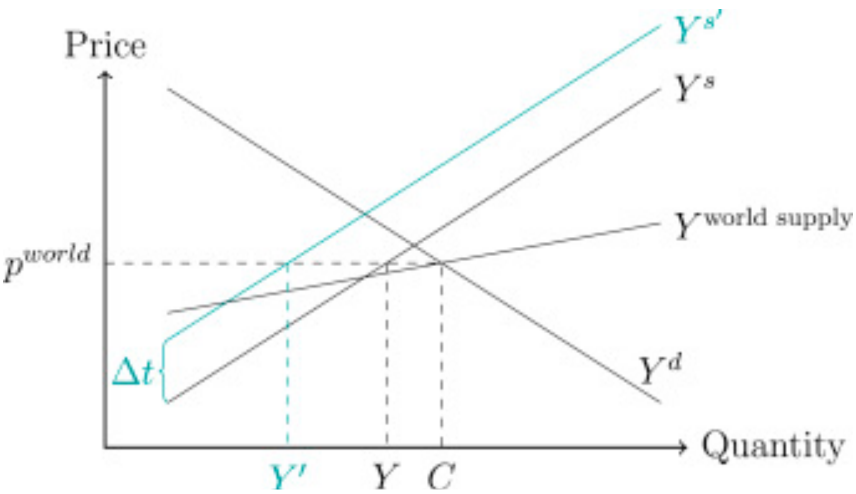
Figure 1: Carbon leakage through the competition channel



Notes: figure was obtained from the paper by Cameron & Baudry (2023)

Most empirical literature investigating carbon leakage through the competition channel looks at the effect of environmental stringency on trade flows. This is because both competition channel effects translate directly into a change in trade flows. For a given level of domestic consumption of a carbon-intensive good, carbon leakage leads to a higher share of imports/total consumption of the home region, and to a lower share of exports/total consumption. Figure 2 explains this using a stylized illustration.

Figure 2: Stylized illustration of the pollution haven hypothesis.



Notes: figure was obtained from the paper by Naegele & Zaklan (2019)

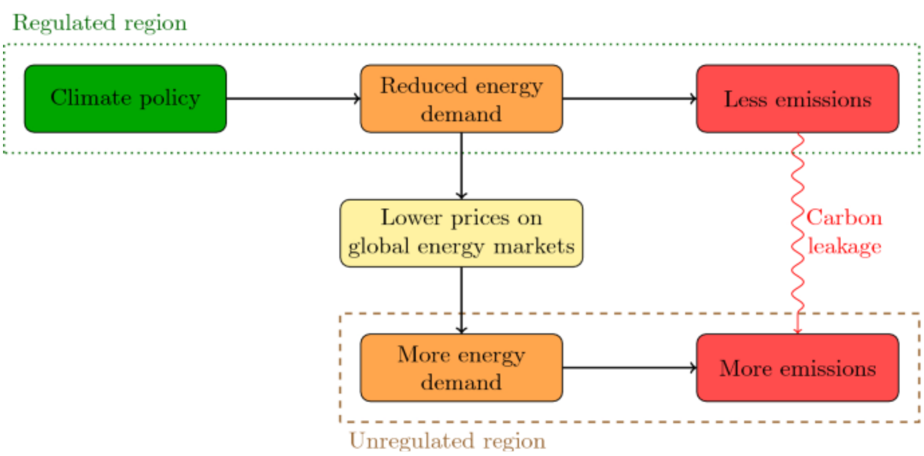
Consider the case of a homogenous good, with immobile production factors in a large country under a neo-classical model. Without an environmental policy, the country produces Y units and consumes C units, such that the difference between Y and C is imported from abroad. When an environmental policy is imposed (i.e., a carbon tax), the supply curve shifts upwards by Δt. As a result, domestic production declines to Y'. Given a constant level of domestic consumption (C), the country will have to import more goods from abroad. If production is equally emission-intensive everywhere in the world, then the total domestic emission reduction is entirely replaced by an increase in foreign emissions. This means that the total effect for global emission mitigation is zero and carbon leakage is 100% (Naegele & Zaklan, 2019).

In theory, this suggests that an increase in environmental stringency will lead to a higher share of net imports/total consumption for the regulated country. However, in practice, the empirical evidence finds contrasting results. The next section will explore the empirical evidence on this topic, but first I will discuss the other two carbon leakage channels.

ii) Energy Channel

Carbon leakage through the energy channel occurs when more stringent environmental regulations lead to a decline in demand for fossil fuels by regulated firms, resulting in a drop in international fuel prices. In turn, the lower fuel prices incentivize unregulated foreign firms to increase their consumption, resulting in increased (carbon) emissions abroad. The energy channel is the least discussed channel of carbon leakage by policymakers, but the empirical literature does consider it to be an important mechanism. Figure 3 below provides a visual representation of how carbon leakage occurs through the energy channel.

Figure 3: Carbon leakage through the energy channel

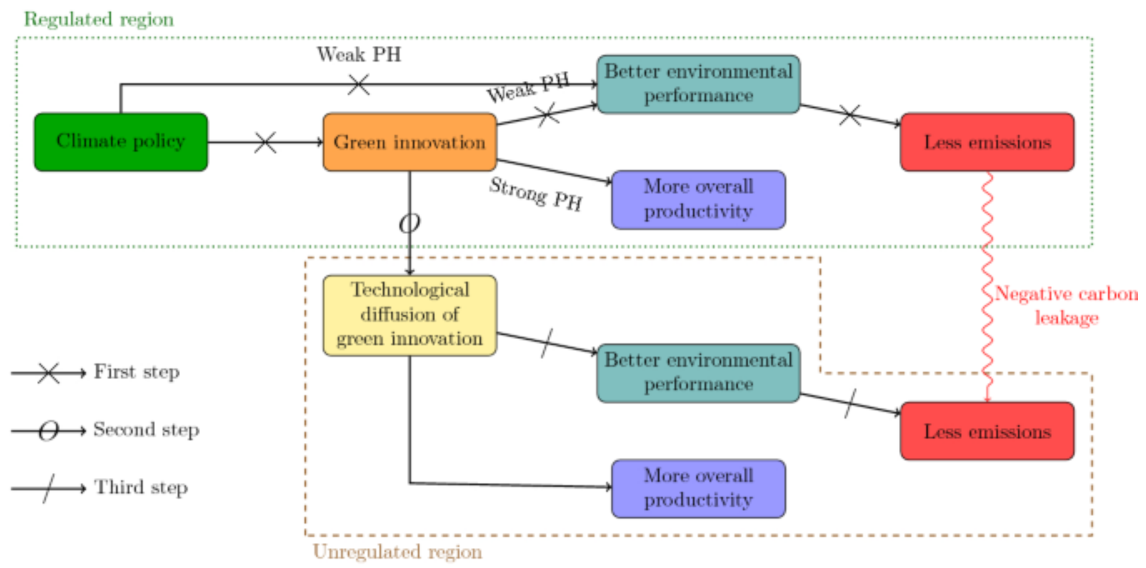


Notes: figure was obtained from the paper by Cameron & Baudry (2023)

iii)   **Innovation Channel (Porter Hypothesis)**

Thirdly, negative carbon leakage can occur through the innovation channel, also known as the Porter hypothesis. In contrast to the previous two channels, the innovation channel leads to a reduction in carbon leakage. According to the Porter hypothesis, when a region imposes an environmental policy, this incentivizes domestic firms to invest in R&D in order to develop low-carbon innovations (Porter & van der Linde, 1995). The Weak Porter hypothesis argues that climate policy can be seen as a driver for innovation, leading to improved environmental performance. The Strong Porter hypothesis goes further and suggests that environmental regulations can improve environmental performance as well as economic competitiveness, due to the productivity gains. If these innovations are successfully diffused abroad, this may result in a decline in global emissions, hence resulting in negative carbon leakage. Figure 4 below provides a visual representation of how the innovation channel results in negative carbon leakage.

Figure 4: Negative carbon leakage through the innovation channel



Notes: figure was obtained from the paper by Cameron & Baudry (2023)

Empirical evidence on Carbon Leakage

Carbon leakage is an important concern among policymakers looking to implement more stringent environmental regulations. Hence, it is important to assess the empirical evidence on the relationship between environmental stringency and carbon leakage. The literature consists of two main strands, the first aim to predict the carbon leakage effect through an ex-ante approach, and the second investigate ex-post evidence.

i) Ex-ante literature

Researchers have used computable general equilibrium (CGE) models to assess ex ante the amount of carbon leakage caused by unilateral climate policies. CGE models are large numerical models which combine economic theory with real economic data in order to derive computationally the impacts of policies or shocks in the economy (Scottish Government, 2016). CGE models are widely used by governments, academics, international organizations and private sector consultancies.

The results of the CGE differ depending on the parameters used and the assumptions of the model. The studies aim to investigate the effect of the policy on the carbon leakage rate, which is defined as the rise in emissions in the rest of the world divided by the abated emissions in the regulated region (Branger & Quirion, 2014). For example, a 20% leakage rate implies that 20% of the emission reduction is offset by an increase in emissions in the unregulated region (i.e., domestic emissions fell by 5%, but foreign emissions increased by 1%). This should not be confused with the misguided interpretation that 20% of emissions have leaked in the unregulated regions. In theory, it is possible that the leakage ratio can be greater than 100%, indicating that the domestic mitigation efforts are more than offset by increases in carbon emissions abroad. This would result in an increase in global emissions as a result of the policy. This is possible because the carbon intensity, which is the amount of carbon used to produce a unit of a product, differs between countries. This is a consequence of differences in the energy sources and production methods used in each country.

Branger & Quirion (2014) conducted a review of the studies investigating carbon leakage and find that environmental policies induce carbon leakage rates of 5-20%. This review includes the studies done by Ghosh et al (2012) and Bohringer et al (2014). Moreover, Carbon & Rivers (2017) also conduct a review of the literature and find carbon leakage rates to be in the range of 10 to 30%. The only outlier study is Babiker et al (2003), who finds a leakage rate of more than 100 percent in one of his simulations.

Although the ex-ante literature tends to find that environmental stringency is positively related to carbon leakage, the ex-post literature is more divided on this. I summarize the ex-post literature in the following section.

ii) Ex-post literature

In contrast to the ex-ante literature, ex-post studies investigate the outcomes after the environmental regulations have been put in place. A handful of studies have investigated the effect of different environmental policies on net trade flows to identify whether carbon leakage has occurred. Table 1 presents an overview of the ex-post literature.

i) US pollution haven – old studies

The earliest environmental regulations were imposed by the US, such as the Clean air act in 1970. Given that climate change was not yet an important topic of interest, researchers studying these early environmental regulations looked at its effect on firm competitiveness, in order to test the pollution haven hypothesis (Kalt, 1985) (Tobey, 1990) (Grossman & Krueger, 1991) (Jaffe et al, 1995). Typically, these studies examine the relationship between the stringency of environmental regulations, as measured by the Pollution Abatement Cost (PAC), and net trade flows. Tobey (1990) and Jaffe et al (1995) both find little to no evidence to support the hypothesis that environmental regulations have caused trade patterns to deviate. On the contrary, Kalt (1985) finds that the overall regulatory policies have had a negative effect on US trade performance.

ii) US pollution haven – recent studies

Dechezleprêtre & Sato (2017) conduct a review on the more recent literature on the impacts of environmental regulations on firms' competitiveness. The evidence shows that implementing ambitious environmental policies can lead to small, statistically significant, adverse effects on trade, especially in pollution-and energy-intensive sectors. However, they find that the cost burden of environmental policies is very small. Hence, it is a minor determinant of trade and investment location choices compared to other factors, such as transport costs, human and natural capital availability. However, in recent years, the cost burden of environmental policies has increased due to the rising carbon tax rates, justifying why my research topic is important to investigate and may lead to other outcomes.

Ederington & Minier (2003) find, using an instrumental variable approach, that environmental policy had a strong positive impact on net imports. This suggests that carbon taxation, would lead to an increase in net imports, and therefore carbon leakage. In contrast, Ederington et al (2005) look at the environmental stringency on trade flows, measured by the ratio of pollution abatement costs to total costs of materials. They try to explain why the effect of environmental regulations on trade may be difficult to detect. They find that for most industries, pollution abatement costs (to reduce or eliminate the negative effects of pollution) represent a very small component of total production costs, and therefore have little effect on trade flows.

Levinson (2010) investigates whether the US is offshoring pollution by importing polluting goods (i.e. carbon leakage). His results show that from 1972 to 2001, the composition of U.S. imports shifted toward relatively clean goods, rather than polluting goods, suggesting that the offshoring of pollution has not occurred.

iii) Kyoto protocol

Aichele & Felbermayr (2015) complete the first empirical ex-post evaluation of the Kyoto protocol, to assess whether ratification of the protocol led to carbon leakage. The Kyoto Protocol is an international agreement that sets binding emission targets for most industrialized countries. The authors adopt a difference-in-difference approach to investigate whether the protocol (treatment) affected the net imports, in embodied carbon, of the committed countries. They conclude that Kyoto has increased committed countries' embodied carbon imports from noncommitted countries by around 8%, indicating that carbon leakage has taken place.

iv) EU ETS

The EU ETS, introduced in 2005, is a market-based cap-and-trade system that sets an absolute quantity limit on CO2 emissions on 12,000 emitting facilities within the European Union (Ellerman & Joskow, 2008). The system has been adopted by the 27 EU member states plus Iceland, Liechtenstein, and Norway, and covers around 40 percent of the EU's total greenhouse gas emissions (European Commission, 2023). The main goals of the ETS are to reduce emissions by increasing energy efficiency and stimulating low carbon technological innovation. However, there have also been concerns that the ETS may lead to carbon leakage.

Several studies have investigated how the EU emission trading system (ETS) has affected carbon leakage, either on a national, sectoral or firm level. On the firm level, Dechezleprêtre et al (2022) investigate whether multinationals have relocated their emission-intensive activities because of the EU ETS. They find no evidence to support this, and therefore conclude that modest differences in carbon prices between countries do not induce carbon leakage. Moreover, Koch & Basse Mama (2016) and Borghesi et al (2020) investigate whether the EU ETS has induced a higher level of firm relocations, measured through an increase in outbound FDI. Both papers find a positive but very weak result, suggesting that carbon leakage is limited.

On the sector level, Reinaud (2008) and Sartor (2013) find no evidence for the EU ETS causing carbon leakage in the aluminium sector, while Branger et al (2016) find no leakage in the cement and steel sector. Moreover, Naegele & Zaklan (2019) analyse the effect of the EU ETS system on carbon leakage in the manufacturing sector, using a DiD estimator. They find no evidence that the EU ETS caused carbon leakage.

On the national level, Verde (2020) finds no evidence of the EU ETS causing carbon leakage.

v) Policy-induced energy prices

Misch & Wingender (2021) use policy-induced energy prices as an alternative variable for carbon prices, to estimate its variation on carbon embodied trade flows. They argue that policy-induced energy prices are a good alternative because they are better available, have more variation than carbon prices and have similar economic and environmental consequences. They find significant results for carbon leakage, depending on the country size and its openness to trade.

vi) All climate policies

Eskander & Fankhauser (2021) investigate the effect of climate change legislation in 98 countries between 1997 and 2017. They find no evidence that international carbon leakage has increased over the past two decades as result of domestic climate regulations. In fact, they find that the long run carbon leakage may even be negative in high income countries.

vii) Carbon tax

To my knowledge, carbon leakage caused by carbon taxation has so far only been evaluated empirically by The World Bank (2008). Using industry data from the OECD countries in the period of 1988 to 2005, The World Bank investigated whether carbon taxation has affected bilateral trade flows. They find that bilateral trade flows are negatively affected (i.e., net imports rise) when an importing country imposes a carbon tax. Moreover, they find a slight increase in the import-export ratio of energy intensive industries in developed countries, and a slight decline in developing countries, providing some support that carbon leakage may have occurred as a result of the taxation.

However, Aichele & Felbelmayr (2015) argue that this study cannot address the issue of carbon leakage properly as they only looked at the change in trade flows measured in value added and did not consider differences in sectoral, country-specific carbon intensities. Differences in carbon intensities between countries can significantly affect the level of carbon leakage. For example, if a country has a relatively high carbon intensity (it produces more emissions per unit of economic output), its firms may face a greater cost burden from a carbon tax compared to firms in countries with lower carbon intensities. This could make those firms less competitive and more likely to relocate to countries with weaker climate policies or lower costs, leading to higher carbon leakage. Also, if firms in the foreign country have a higher carbon intensity than in the regulated country, then a relocation of firms abroad will lead to a higher leakage rate (as total emissions abroad would increase more than if the carbon intensity was equal in both countries). Hence, the total size of carbon leakage is higher when firms relocate to countries where the carbon intensity is higher.

Therefore, in order to accurately measure the carbon leakage effect, it is important to measure the carbon content of trade, rather than the value of trade. Changes in the carbon content of trade reflect total emission changes in a trade partner and thus allow testing for leakage (Aichele & Felbelmayr, 2015).

Hypothesis

The theory and literature are divided on the effect of environmental policies on carbon leakage. According to the pollution haven channel and energy channel theories, carbon taxes would lead to more leakage, whereas Porter's theory suggests the opposite effect. The ex-ante literature predicts increases in net imports caused by environmental policies, indicating carbon leakage. However, the ex-post empirical evidence is inconclusive on the evidence for carbon leakage.

I expect that the recent higher levels of carbon taxes act as a strong incentive for firms to offshore their production. Therefore, I formulate the following hypothesis:

H1: *Within the EU ETS, countries with carbon taxes will have higher levels of net CO2 embodied imports/total CO2 compared to countries without carbon taxes, which would indicate that carbon leakage has occured.*

Table 1: Overview of ex-post literature

Author & Year	Time period	Context	Method & Policy	Policy/ Explanatory variable	Results
Ederington & Minier (2003)	1978-1992	US, manufacturing	Instrumental variable	US pollution abatement costs	Find evidence for carbon leakage
Ederington et al 2005	1978-1992	US, all industries	OLS regression	US pollution abatement costs	No evidence for carbon leakage
Worldbank (2008)	1988-2005	OECD countries	Standard gravity model	Multiple environmental policies, including carbon taxes	Limited evidence of carbon leakage
Reinaud (2008)	1999-2006	EU ETS, aluminum sector	Linear regression model - prais winsten estimation. Time series	EU ETS phase I	No evidence for carbon leakage
Levinson (2010)	1972-2001	US imports	OLS regression	N/A	Finds that US imports is not offshoring pollution by importing pollutive goods, hence no evidence for leakage
Rahel Aichele and Gabriel Felbermayr (2011, 2015)	1995-2007	40 countries, 12 industries	Fixed effects & Differences in differences	Kyoto Protocol	Kyoto protocol increased carbon leakage
Sartor, 2013	1999-2011	EU27 countries, Aluminum sector	OLS regression	EU ETS Phases I & II	No evidence for carbon leakage
Branger et al. (2016)	1999-2012	Phases I and II of EU ETS, Cement and steel sectors	ARIMA regression and Prais winsten estimation	EU ETS phases I & II	No evidence for carbon leakage
Naegele & Zaklan (2019)	2004, 2007 & 2011	66 regions, 25 manufacturing sectors	OLS regression	EU ETS	No evidence for carbon leakage
Koch & Basse Mama (2019)	1999-2013	German Multinational firms	Difference in difference	EU ETS	No evidence for relocation of firms, limited evidence for leakage
Borghesi (2020)	2002-2010	22,000 Italian manufacturing firms, EU ETS	Differences in difference	EU ETS phase I	Limited evidence for carbon leakage
Misch & Wingender (2021)	2005-2015	38 countries, 21sectors	OLS regression	Changes in energy prices	Some evidence for carbon leakage in certain countries
Eskander S, Fankhauser S (2021)	1997-2017	98 countries	Two-way fixed effect panel regression	Multiple Climate change laws	No evidence for carbon leakage
Dechezleprêtre et al. (2022)	2007-2014	1,122 companies, 261 subject to EU ETS	OLS regression	Energy price index / Environmental policy stringency	No evidence for carbon leakage

3. Methodology & Data (Empirical Approach)

i) Methodology

To estimate the effect of carbon taxation on carbon leakage, I adopt the methodology proposed by Ederington et al (2005). This method regresses net trade data in embodied carbon and in added value, on a measure of environmental stringency, which is carbon taxation in my analysis. This model is an extension of the model of Grossman & Krueger (1991) and is has been commonly used in the literature, making it appropriate for the purpose of this study (Naegele & Zaklan, 2019) (Sartor, 2013) (Branger et al, 2016).

In this study, I employ a fixed effects model to obtain unbiased estimators. I have performed diagnostic tests in section 4 to confirm that this is the most appropriate estimator. A fixed effects model is a statistical regression model used to analyse panel data. By including fixed effects, the model controls for time-invariant characteristics, which helps to eliminate the bias resulting from these unobserved factors. Hence, by employing this approach, I can better isolate the effect of carbon taxation on net trade flows and assess whether carbon leakage has occurred.

The baseline model looks as follows:

$$(1)\ Y_{it} = \alpha_0 + \alpha_1 CT_{it} + \beta_1 X_{it} + \eta_i + \eta_t + \varepsilon_{it}$$

Where Y_{it} denotes the outcome variable, which are the net trade flows, in value added and in embodied carbon, for country i in year t. CT_{it} is my explanatory variable and captures the effect of the carbon tax. For the main analysis, I use the carbon tax rate as the explanatory variable. In other regressions, CT_{it} is denoted as a categorical variable to represent different carbon tax rate groups. In the robustness checks, I also use government revenue from carbon taxation as an alternative explanatory variable. X_{it} is a set of covariates which are selected based on economic reasoning and previous literature (Aichele & Felbermayr, 2011) (Naegele & Zaklan, 2019) (Branger et al, 2016) (Sartor, 2013). The covariates are GDP, industry share of GDP, import duties (revenue as a % of GDP), real effective exchange rate, CO2 intensity, energy use, and environmental policy stringency index. Furthermore, η_i and η_t capture the country and year fixed effects. ε_{it} denotes the error term.

ii) Data

The data for this research is obtained from the OECD and World Bank databases. The OECD contains detailed data on carbon embodied trade flows for 65 economies from 1995 until 2018, data on the stringency of environmental policies and revenues from customs and import duties. Furthermore, the World Bank provides data on the height of carbon taxes, as well as data for different control variables.

The data from the OECD and World Bank are used to construct one dataset, which combines trade data with carbon pricing data. Carbon leakage can be measured on 3 levels: national, sectoral or firm. For the purpose of this study, I have chosen to investigate carbon leakage on the national level. I have chosen to exclusively analyse countries that are part of the European Union Trading System (EU ETS). These countries share similar characteristics with respect to climate policies, except that they differ in terms of their carbon taxation. Therefore, I can better isolate the different effects that carbon taxation may have on carbon leakage, without the distortion effect caused by the EU ETS itself.

The EU ETS currently operates in 30 countries, which includes the 27 EU member countries as well as Iceland, Liechtenstein and Norway. Additionally, the United Kingdom was part of the EU ETS until January 2021, due to Brexit (European Commission, 2023). These countries are important to investigate because they are among the largest importers of carbon emissions in the world.

Several observations were dropped in order to construct the final dataset. Due to missing carbon embodied trade data for Liechtenstein, this country was dropped from the dataset. Although the UK is no longer part of the EU ETS, I chose to include the country as it was part of the EU ETS for the full duration of my dataset. My dataset is restricted from 1995 until 2018 due to the availability of OECD trade data. The final sample therefore comprises of 30 countries in the time period from 1995-2018. An overview of the countries in my sample is found in table 17 in the appendix.

i) Data on trade flows

Following Aichele & Felbermayr (2015) and Naegele & Zaklan (2019), my main outcome variable are net trade flows, measured both in value added (% of GDP) and in embodied carbon (million tonnes of CO2 equivalent). The net trade flows in embodied carbon are the sum of CO2 emissions from all sources that are used as inputs for traded goods and services. In order to account for differences in country sizes, net trade flows in value added are scaled by GDP and net trade flows in embodied carbon are scaled by total final domestic demand of CO2 emissions. The net imports in value added are constructed using data obtained from the World Bank, whereas the net imports in embodied carbon are constructed using OECD data.

According to the literature, net imports in embodied carbon provide a more accurate representation of carbon leakage than trade flows in value added. This is because trade flows in embodied carbon directly capture the displacement of CO2 emissions, whereas trade flows in value added simply measure the monetary value of trade. Moreover, this measure also accounts for the differences in CO2 intensity between countries. This is important because a relocation of production activities towards an unregulated region is less of a problem if the unregulated region produces less CO2 emissions per unit of output, compared to the regulated region. This implies that there could be leakage in economic terms as a result of the policy, but this does not necessarily imply carbon leakage.

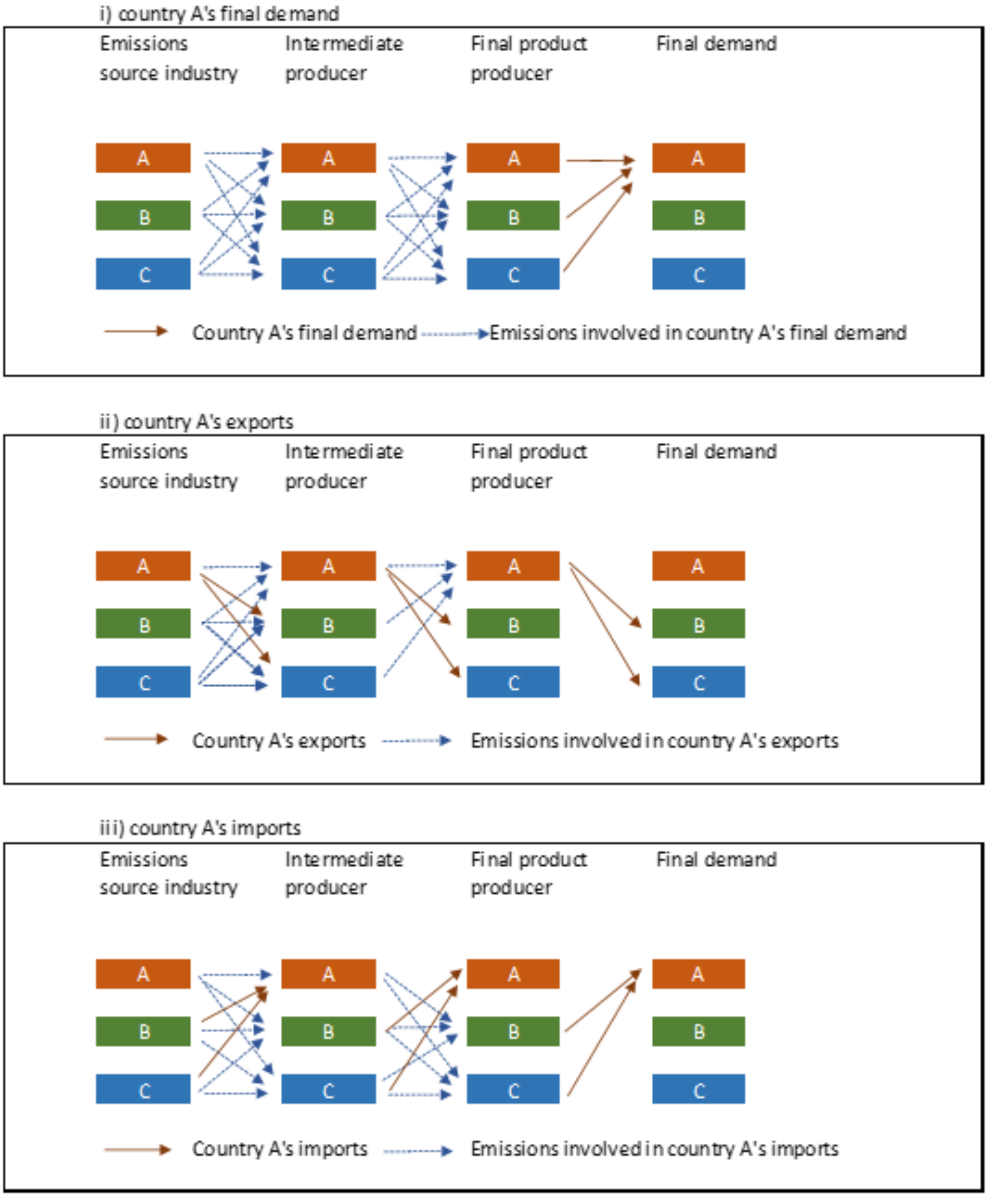
I will use the newly created dataset by the OECD on carbon dioxide emissions embodied in international trade (OECD, 2020). This provides import and export data for 65 economies and all sectors from 1995 to 2018. The dataset was constructed by Yamano & Guilhoto (2020). The authors explain their methodology and discuss their key findings in their working paper. In order to estimate the carbon emissions embodied in final demand and international gross trade, they use the OECD's inter-country input-output (ICIO) tables in combination with the international energy agency (IEA) CO2 emissions from fuel combustion statistics.

Figure 5 below provides a visual representation on how the authors calculated the carbon embodied trade flows. Panel I shows how each country's final demand of total CO2 emissions is determined; by adding all the CO2 emissions produced domestically and imported from abroad (via intermediate producers). Panel II shows a country's exports of CO2 emissions and panel III shows the imports of CO2 emissions. For my dataset, I am interested in the net imports of CO2. Hence, I use the difference between panel II and panel III to calculate the net CO2 imports. I then normalise this to account for differences in country size, by dividing the net CO2 imports by the total final CO2 demand (panel I):

$$(2)\ Y = \frac{Co2\ imports - Co2\ exports}{Co2\ final\ demand} = \frac{Net\ CO2\ imports}{CO2\ final\ demand}$$

Throughout this paper, I may interchangeably use net imports in embodied carbon or net CO2 imports. In both cases, I am referring to the outcome variable in formula 2 above.

Figure 5: Construction of carbon embodied trade flow variables

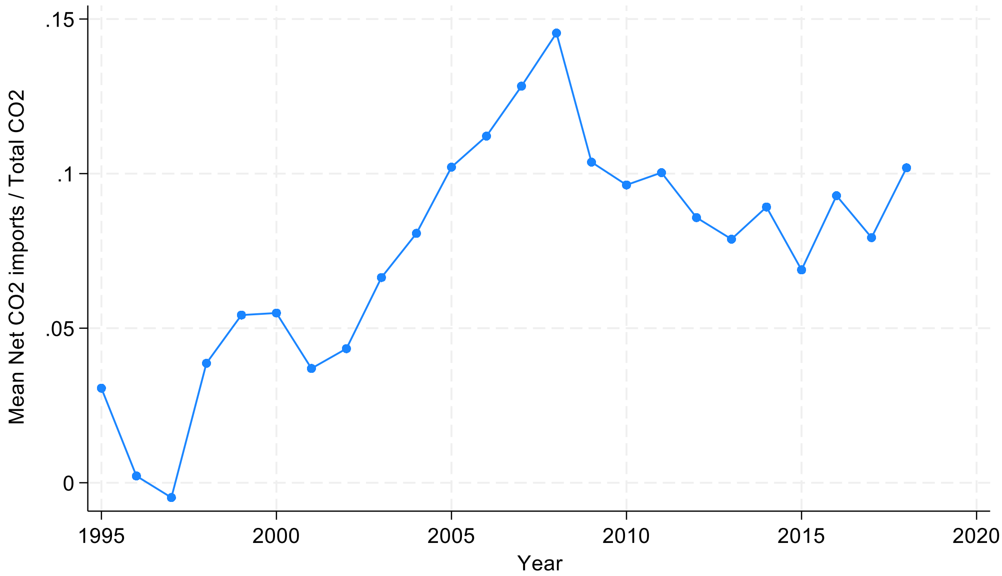


Notes: figure was obtained from the paper by Yamano & Guilhoto (2020)

The paper by Yamano & Guilhoto (2020) find some interesting trends regarding the flow of carbon emissions. They find that China is the main exporter of CO2 emissions whereas the United States is the main importer.

Figure 6 below shows the trend of net CO2 imports in my sample from 1995-2018. On average, the net CO2 imports in the sample countries has increased. It also noticeable that there is a clear drop in the net CO2 embodied imports in 2008, which coincides with the financial crisis. The net CO2 embodied imports have not recovered to the pre-crisis level during my sample period.

Figure 6: Average net CO2 imports / Total CO2 from 1995-2018



Notes: Figure 6 shows the net CO2 imports as a ratio of domestic CO2 demand, averaged out across all countries in the sample from 1995-2018. Formula (2) is used to compute the Y-axis variable. The figure is constructed by the author using data from the OECD on carbon embodied trade flows.

ii) Data on carbon taxation

Similar to Franx & Dijkgraaf and The World Bank (2008), carbon taxation is used as the measure of environmental stringency. The data is obtained from the carbon pricing dashboard of the World Bank (World Bank, 2023). This dataset provides information on the carbon price, scope of taxation and the government revenue for all countries from 1990-2023.

For the purpose of this paper, I am interested in investigating whether differences in the carbon tax between countries lead to different effects on carbon leakage. Hence, the carbon tax rate is my explanatory variable. I also construct a categorical variable to create 4 distinct tax rate groups. This allows me to observe whether the leakage effects are different at higher tax rates.

Additionally, I also use an alternative explanatory variable in my robustness analysis. This variable measures the government revenue obtained from carbon tax, which captures a combination of the tax level and its coverage. In order to account for differences between the size of countries, I normalise this variable by dividing by the country's GDP.

I follow the convention in the literature to lag all explanatory variables by 1 year across my models, and by multiple years in the robustness checks. This is because the decision to offshore emission intensive production abroad is likely to have a delay after an environmental policy (i.e., carbon tax) has been implemented. Existing literature has shown that firms react to environmental policies relatively fast, usually after 1-2 years (Franco & Marin, 2017) (van Leeuwen & Mohnen, 2017). Moreover, lagging the explanatory variable also reduces the concerns of reverse causality.

Table 2 below lists the countries of my sample that have implemented a carbon price. I have chosen to include the United Kingdom as it was part of the EU ETS throughout the sample period. Luxembourg, the Netherlands and Austria have implemented a carbon taxation after 2018 and are therefore considered untaxed countries in my paper.

Table 2: Countries with Carbon Taxation

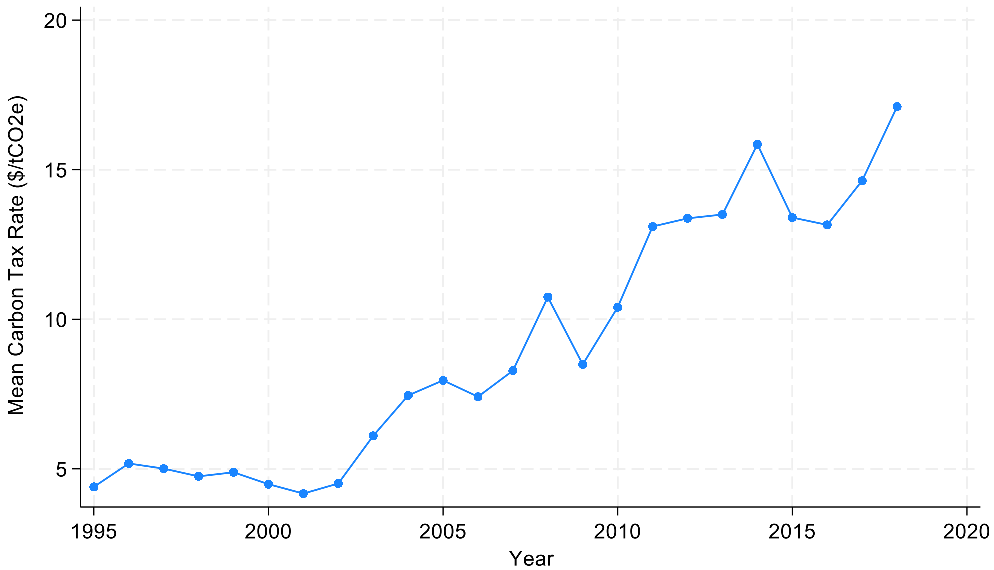
#	Countries	Year of Carbon tax implementation	Year joined EU ETS	Carbon tax rate (per ton of CO2e) in 2022		Share of jurisdiction's Greenhouse gas emissions covered in 2022	Government revenues in USD million (in 2021)***
				Euro	USD		
1	Finland (FIN)	1990	2005	€ 77.00	$ 85.00	36.00%	$ 1547
2	Poland (POL)	1990	2005	€ 0.07	$ 0.08	3.75%	$ 1
3	Norway (NOR)	1991	2008	€ 79.12	$ 87.61	63.00%	$ 1716
4	Sweden (SWE)	1991	2005	€ 117.30	$ 129.89	40.00%	$ 2267
5	Denmark (DNK)	1992	2005	€ 24.04	$ 26.62	35.00%	$ 468
6	Slovenia (SVN)	1996	2008	€ 17.27	$ 19.12	51.93%	$ 145
7	Estonia (EST)	2000	2005	€ 2.00	$ 2.21	5.61%	$ 2
8	Latvia (LAT)	2004	2005	€ 14.97	$ 16.58	3.00%	$ 7
9	Iceland (ISL)	2010	2008	€ 30.93	$ 34.25	55.00%	$ 48
10	Ireland (IRL)	2010	2005	€ 40.92	$ 45.31	40.00%	$ 542
11	United Kingdom (GBR)	2013	2005-2020*	€ 21.36	$ 23.65	21.00%	$ 690
12	France (FRA)	2014	2005	€ 44.51	$ 49.29	35.00%	$ 8400
13	Spain (ESP)	2014	2005	€ 14.97	$ 16.58	1.87%	$ 77
14	Portugal (PRT)	2015	2005	€ 23.88	$ 26.44	36.00%	$ 331
15	Luxembourg (LUX)**	2021	2005	€ 39.15	$ 43.35	65.00%	$ 241
16	Netherlands (NLD)**	2021	2005	€ 42.00	$ 46.14	11.70%	N/A
17	Austria (AUT)**	2022	2005	€ 30.00	$ 33.15	40.30%	N/A

Notes: *The UK was part of the EU ETS during the sample years and is therefore included in the study. **For these countries, the carbon tax was implemented after the sample years. Hence, they are considered untaxed countries for this study. *** Previous year is used because government revenues were calculated at end of year. I use the unit of currency as USD in my regression analysis because GDP per capita and import duty revenues are also denoted in USD.

Table 2 lists the carbon tax rates, the scope (share of greenhouse gas emission's covered) and the government revenue per country in 2022. It is noticeable that the carbon tax rate differs greatly between countries, with Sweden having the highest carbon tax and Poland the lowest. Countries also differ greatly in terms of the scope of the tax, whereby Luxembourg's carbon tax covers 65% of their greenhouse gases and the carbon tax in Spain only 1.9% in 2022. My variable of interest is the government revenue from the carbon tax, which is largest in France ($8.4 billion), and smallest in Poland ($1 million). Given these large discrepancies between countries, it is plausible that the tax has different effects on the size of carbon leakage in each country.

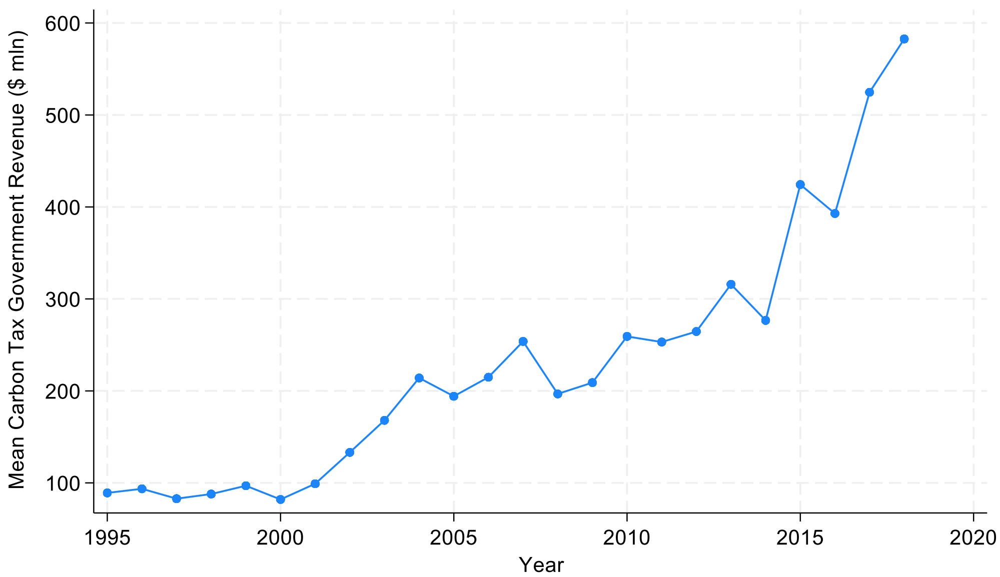
Figures 7 and 8 illustrate how the average the carbon tax rate and government revenue from carbon taxes have increased during my sample period from 1995-2018.

Figure 7: Average carbon tax rate ($/tCO2e) in sample countries from 1995-2018



Notes: This figure shows the evolution of the average carbon tax rate across the countries in my sample from 1995-2018.

Figure 8: Average government carbon tax revenue ($ million) in sample countries from 1995-2018



Notes: This figure shows the evolution of the average government revenue from carbon taxation across the countries in my sample from 1995-2018. Government revenues are measured in millions of $, and is the total revenue from the previous year.

iii) Covariates

In order to investigate the effect of carbon taxation on net trade flows, several covariates were included in the analysis to control for confounding variables and improve the accuracy of the model. These covariates were carefully selected based on economic reasoning and previous literature (Aichele & Felbermayr, 2011) (Naegele & Zaklan, 2019) (Branger et al, 2019) (Sartor, 2013). The covariates used in this study are listed in table 3 and include: GDP, industry share of GDP, import duty revenues, real effective exchange rate, CO2 intensity, energy use, and environmental policy stringency index.

Table 3: List of variables

Variable name	Indicator	Measure	Source
Net CO2 imports	CO2 emissions embodied in net imports of goods and scaled by total domestic carbon demand	Ratio	OECD I-O Database
Net imports	Net imports of goods and services (% of GDP)	%	WDI
Carbon tax level	Level of carbon price in country's jurisdiction	USD	World Bank Carbon Pricing Dashboard
Government Revenue	Total government revenue from carbon tax (incorporates price level and share of jurisdiction's emissions covered)	USD	World Bank Carbon Pricing Dashboard
GDP	Gross domestic product per capita	USD per capita (constant 2015)	WDI
Industry	Value added of Industry (including construction)	% of GDP	WDI
Import duty revenues	Revenue from customs and import duties (% of GDP)	%	WDI
Exchange rate	Real effective exchange rate index	Index (2010=100)	WDI
CO2 intensity	Amount of CO2 emitted per unit of energy consumed	CO2 (kg) emitted per kg of oil equivalent (kgoe) energy use	WDI
Energy use	Amount of energy consumed per capita	Kg of oil equivalent per capita	WDI
Environmental Stringency	Degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviour.	Index from 0 to 6	OECD

GDP is included as a covariate to account for the overall economic activity of countries. It is expected that the coefficient of GDP is positive because as domestic consumption rises, residents are likely to import more goods and services from abroad. Following Branger et al (2016), the industrial sector size variable was included to capture the level of industrialization. The expected sign of the coefficient of industrial structure is negative. A large industrial sector is associated with high levels of (emission-intensive) production, of which a large component is likely to be exported abroad.

To control for trade barriers imposed by the countries in the sample, I have included import duty revenues. This variable is a measure of the total revenues from custom and import duties, normalised by the country's GDP. By controlling for revenues, I account for both the import duty rate and the quantity of products subject to duties. The expected coefficient of import duty revenues is negative, because higher import duty revenues, indicating a more stringent trade barrier, would lead to lower net imports. The issue with the import duty revenues is that the variable could be endogenous, as it is may be dependent on net imports, resulting in reverse causality. I expect that this might be an issue when using net imports in value added as the outcome variable, but it should not pose major issues for the model with net imports in embodied carbon. Alternatively, using the mean applied tariff rate would be less informative because this rate is equal for all EU countries and therefore fails to capture any heterogeneity across countries.

Moreover, the real effective exchange rate (REER) was included to account for currency fluctuations and changes in price and cost competitiveness. The REER measures the value of a country's currency in relation to its trading partners, taking costs and price differences into account (European Parliament, 2017). Since most of the sample countries used the same currency (Euro), the REER is a better measure of price competitiveness than the nominal exchange rate. The expected sign of the REER is positive, because when a country's currency appreciates, imports become relatively cheaper, resulting in increased net imports.

CO2 intensity, as a covariate, aims to capture the efficiency of production within countries. Energy use is considered to account for the overall energy consumption patterns. The expected signs of CO2 intensity and energy use are ambiguous.

Lastly, environmental stringency was included as a covariate to control for other regulatory measures and environmental policies implemented by countries. The sign may be positive in the case of the pollution haven hypothesis, and negative in the case of Porter's hypothesis.

iv) Descriptive statistics

The descriptive statistics in table 4 provide a summary of the key characteristics for taxed and untaxed countries. My final dataset includes 30 EU ETS countries (including UK), of which 14 countries had a carbon tax in place during the 23-year sample period from 1995-2018.

Table 4: Descriptive Statistics

Taxed countries	Obs	Mean	Std. Dev.	Min	Max
Net imports (embodied carbon)	336	.084	.159	-.374	.433
Net imports (% of GDP)	336	-.016	.072	-.288	.206
Carbon tax rate ($)	336	19.496	33.447	0	168.826
Government revenue from tax ($mln)	336	491.951	1045.154	0	9262.953
Lag of government revenue	322	1.353	2.091	0	9.714
GDP per capita	336	33921.251	18202.965	4969.823	75953.582
Log of GDP per capita	336	10.25	.655	8.511	11.238
Industrial sector (VA % of GDP)	336	25.078	4.869	17.188	40.295
Import duty revenues (% of GDP)	336	.223	.318	0	2.965
Exchange rate	288	101.574	12.789	69.842	156.978
CO2 intensity (kg of CO2 per kgoe)	293	2.091	.798	.326	3.489
Log of CO2 intensity	293	.639	.492	-1.12	1.25
Energy use (Kgoe per capita)	293	4448.328	2927.929	1618.46	18178.139
Log of energy use	293	8.264	.481	7.389	9.808
Environmental policy stringency index	264	2.416	1.007	0	4.556

Untaxed Countries	Obs	Mean	Std. Dev.	Min	Max
Net imports (embodied carbon)	384	.066	.181	-1.215	.381
Net imports (% of GDP)	384	-.012	.09	-.338	.197
Carbon tax rate ($)	384	0	0	0	0
Government revenue from tax ($mln)	384	0	0	0	0
Lag of government revenue	368	0	0	0	0
GDP per capita	384	26469.947	22660.96	3537.318	112417.88
Log of GDP per capita	384	9.88	.784	8.171	11.63
Industrial sector (VA % of GDP)	384	23.987	6.124	9.973	40.212
Import duty revenues (% of GDP)	264	.29	.424	.032	4.274
Exchange rate	358	94.05	12.092	46.221	121.195
CO2 intensity (kg of CO2 per kgoe)	330	2.428	.513	1.214	3.653
Log of CO2 intensity	330	.864	.215	.194	1.295
Energy use (Kgoe per capita)	330	3416.016	1600.524	1591.668	9428.811
Log of energy use	330	8.046	.409	7.373	9.152
Environmental policy stringency index	216	2.319	.866	.361	4.056

On average, the taxed countries have a slightly higher ratio of net imports in embodied carbon as a share of their total CO2 demand compared to untaxed countries. This may be an initial indication that countries with carbon taxes, on average, have slightly higher rates of carbon leakage. However, we must be careful to draw such conclusions at this stage, as the higher net imports may also be determined by other variables. The net imports in value added are negative in both groups of countries, indicating that, on average, both groups are net exporters of goods and services. The average net imports measured in value added are higher (less negative) in untaxed countries, as opposed to taxed countries. This may suggest that taxed countries have lower levels of net imports, but the products traded have a higher carbon content.

The average carbon tax rate is \$19.5 per ton of CO2e, with Sweden having the highest tax rate of \$168.8 in 2008. The average government revenue from carbon taxes is \$491 million, with France having the highest revenue of \$9.3 billion in 2018. These statistics show that although Sweden may have a higher carbon tax rate, the overall impact of the tax rate may be greater in France due to its broader coverage across sectors and firms.

On average, the taxed countries have a higher level of GDP per capita than untaxed countries. Moreover, Taxed countries, on average, have a larger industrial sector and a higher level of energy consumption. This is logical because a high use of energy is associated with more carbon emissions, which justify the implementation of a carbon tax in these countries.

4. Results & Discussion

i) Diagnostic tests

I use a fixed effects (FE) model for this study. I performed several diagnostic tests to confirm that fixed effects is the most suitable regression model. The results of the diagnostic tests are shown in figures 9-11 in the Appendix. Firstly, I conducted a Hausman test to determine whether to use random or fixed effects. The Hausman test gave me a significant P-statistic, implying that a random effects model cannot be used. Using the Breusch-Pagan Lagrange Multiplier, I tested whether to use a random effects or pooled OLS model. Since the P statistic is significant, a Pooled OLS model cannot be used either. Hence, I conclude that a fixed effects model must be used for this panel analysis. For the chosen FE model, I performed a modified Wald test for heteroskedasticity. Since the P-value was significant, I rejected the null hypothesis of homoskedasticity and concluded that there is a heteroskedasticity problem. To correct for this, the fixed effects model uses robust standard errors.

When regressing net trade flows on carbon taxation, it is also important to consider multicollinearity concerns. Multicollinearity exists if there is high correlation between the independent variables, which can lead to unreliable estimates. To identify whether my variables are highly correlated, I construct a pairwise correlation table and use a variance inflation factor, shown in tables 5-7. Table 5 shows that the pairwise correlation between all variables is below the commonly used threshold of 0.7 (Dormann et al, 2013). The only variables that are highly correlated with each other are government tax revenues and carbon tax rates. However, this is not an issue, given that these are alternative explanatory variables and will never be used simultaneously in one regression. I was concerned that the environmental policy stringency index may be correlated with the carbon tax rate, but this correlation is only 0.313. Moreover, the variance inflation factor table shows that all variables fall well below the commonly used threshold of VIF=5 (Dormann et al, 2013). Hence, I conclude that multicollinearity is not a problem in my model.

Table 5: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Net imports (CO2)	1.000										
(2) Net imports (VA)	0.084	1.000									
(3) Government tax revenues	0.161	-0.209	1.000								
(4) Lag of carbon tax rate	0.235	-0.186	0.877	1.000							
(5) Log of GDP	0.326	-0.657	0.365	0.344	1.000						
(6) Industry (VA)	-0.178	0.113	0.119	0.107	-0.273	1.000					
(7) Import duty revenues	-0.203	0.183	-0.122	-0.117	-0.371	0.184	1.000				
(8) Real exchange rate	0.426	-0.087	0.115	0.070	0.496	-0.216	-0.427	1.000			
(9) Log of CO2 intensity	-0.247	0.073	-0.399	-0.442	-0.263	-0.035	0.034	-0.341	1.000		
(10) Log of energy use	-0.024	-0.539	0.312	0.299	0.693	-0.029	-0.112	0.378	-0.586	1.000	
(11) Environmental policy stringency	0.244	-0.246	0.264	0.313	0.410	-0.280	-0.483	0.271	-0.364	0.166	1.000

Table 6: Variance inflation factor with carbon tax rate

	VIF	1/VIF
Log of energy use	3.134	.319
Log of CO2 intensity	2.865	.349
Log of GDP	2.858	.35
Lag of carbon tax rate	2.086	.479
Import duty revenues	1.856	.539
Real exchange rate	1.845	.542
Industry (VA)	1.545	.647
Environmental policy stringency	1.528	.654
Mean VIF	2.215	.

Table 7: Variance inflation factor with government tax revenues

	VIF	1/VIF
Log of energy use	3.105	.322
Log of GDP	2.874	.348
Log of CO2 intensity	2.473	.404
Import duty revenues	1.859	.538
Real exchange rate	1.83	.546
Lag of government tax revenues	1.763	.567
Industry (VA)	1.532	.653
Environmental policy stringency	1.523	.657
Mean VIF	2.12	.

Moreover, it is also important to evaluate the exogeneity of the variables, to avoid potential biases in the results. GDP per capita may be endogenous since net imports in value added is a component of GDP. Hence, changes in net imports may influence GDP. However, this is not an issue for the main results given that I use net imports in embodied carbon as the main outcome variable.

As mentioned earlier, import duty revenues may also be endogenous because it is dependent on the number of imports, which is captured by the outcome variable. Moreover, Energy use may be endogenous because it may be affected by the size of the industrial sector.

The main problem that may occur if these control variables are indeed endogenous is that the estimated coefficients may not represent the true causal effects of the control variables on the outcome variable. As a result, the estimated coefficients may be biased.

To account for these endogeneity issues, I use a stepwise regression approach, such that I also obtain coefficients where import duty revenues or energy use are excluded from the model. Moreover, I conduct several robustness checks and sensitivity checks to see whether the estimates change substantially when different controls are used. To minimize the risk of reverse causality, I lag my explanatory variable by at least 1 year in all my models.

ii) Results

The regression results from the fixed effects specification (1) are provided in table 8. The explanatory variables are added to the model step-by-step. The results in table 8 show some evidence of carbon leakage. The coefficients from the regressions of carbon tax rate on net imports in embodied carbon are positive and significant in models 4-8.

In particular, the coefficient is 0.001 across the models. This means that a $1 increase in the tax rate leads to an increase in the ratio of net imports of embodied carbon to total CO2 of 0.001, ceteris paribus. Alternatively, this means that on average, a 10% increase in the carbon tax rate would result in a 1.2%* increase in net imports in embodied carbon, ceteris paribus, which is economically significant.

The statistically significant explanatory variables were the log of GDP per capita (model 2,3,7) and the real effective exchange rate (model 5,6,7,8). These variables are all positively correlated with the outcome variable. These results suggest that countries with a higher level of GDP per capita and a higher exchange rate tend to import more CO2 emissions from abroad, which is in line with my expectations.

It is also important to note that the relatively small R-squared value may indicate that some important control variables are missing, which could lead to omitted variable bias.

*(10% of Mean tax rate x coefficient / Mean outcome variable) x 100%

Table 8: FE Regression of EU ETS countries' carbon tax rate on net imports (in embodied carbon)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Net embodied CO2 / Total CO2						
Lag of carbon tax rate	0.000	0.001	0.001	0.001**	0.001***	0.001***	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Ln GDP per capita		0.147**	0.123*	0.111	0.061	0.084	0.195
		(0.067)	(0.067)	(0.074)	(0.081)	(0.073)	(0.124)
Industry structure			0.004	-0.001	0.001	0.004	0.002
			(0.006)	(0.004)	(0.004)	(0.004)	(0.006)
Import duty				-0.032	0.001	0.009	0.002
				(0.021)	(0.026)	(0.028)	(0.023)
Real exchange rate					0.003**	0.003**	0.002**
					(0.001)	(0.001)	(0.001)
Ln CO2 intensity						0.051	-0.024
						(0.037)	(0.158)
Ln energy use							0.071
							(0.114)
Environmental policy stringency							0.012
							(0.017)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.001	-1.437**	-1.310**	-1.018	-0.882	-1.251*	-2.705**
	(0.030)	(0.658)	(0.626)	(0.697)	(0.793)	(0.682)	(1.256)
Observations	690	690	690	575	506	439	380
R-squared	0.189	0.221	0.229	0.237	0.342	0.421	0.460
# of Countries	30	30	30	25	22	22	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Carbon tax rates in EU ETS countries have only started rising to substantial levels and expanded in scope in recent years, as depicted by figures 7 and 8. Therefore, it is also relevant to investigate whether different tax rate groups have different carbon leakage rates. I construct a categorical variable that divides the observations into four distinct groups based on the magnitude of their carbon tax rates. Group 1 includes countries without carbon tax rates. Group 2 comprises of countries that have a low carbon tax, Group 3 includes countries with a medium tax and group 4 includes countries with a high tax rate. Table 9 provides a summary of the tax groups and table 10 presents the results of the model.

Table 9: Summary statistics of carbon tax groups

Carbon tax group	Number of values	Mean Carbon tax level ($)
1. No Tax	507	0
2. Low tax	71	2.50
3. Medium tax	71	18.95
4. High tax	71	70.82
Total	720	9.10

The coefficient for all tax groups is negative. This implies that countries with a carbon tax have fewer net CO2 imports (higher net CO2 exports) compared to countries without a carbon tax. As the tax rate group increases, the coefficient becomes increasingly negative. This means that countries in group 4, with the highest tax rate, have the lowest net CO2 imports (highest net CO2 exports) compared to countries without a tax. In other words, this suggests that carbon leakage rates are lowest among countries with the highest carbon taxes. However, most of the results are statistically insignificant. The statistically significant coefficients are those for the low and medium carbon tax groups in the first few models, which only include a few controls, and therefore may not capture the true effect.

I have analyzed when certain controls are removed from the model, such as GDP per capita, as it may be the case that countries with larger GDP have higher tax rates. However, I find that the magnitude and sign of the results does not change substantially.

The finding that higher tax rate groups tend to have lower net CO2 imports compared to groups with lower tax rates contrasts with the findings in table 8 and my hypothesis. I expected that the group with the highest tax rate would have the highest carbon leakage rates. Given that these results indicate the opposite, it seems plausible that Porter's hypothesis is true for this sample. This means that firms in countries with higher carbon taxes are incentivised to invest more in carbon-reducing technologies, rather than offshoring the emission-intensive activities. In the context of policymaking, this is a positive finding because it implies that the consequences of increasing carbon taxation are milder than initially assumed.

However, I believe my results should be interpreted with due caution due to the lack of statistical significance and contrasting results with table 8. The discrepancy between table 8 and 10 may arise due to the presence on confounding variables influencing the relationship between the carbon tax rate and net CO2 imports. It is likely that after splitting the carbon tax rate into different categorical groups, the confounding variables have different distributions within each group, resulting in different coefficients. This may explain why the signs are the opposite in the two result tables.

Table 10: Regression of carbon tax rate groups on net imports (in embodied carbon)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Net embodied CO2 / Total CO2							
2. Low CO2 tax	-0.042	-0.063***	-0.057**	-0.047*	-0.066**	-0.050	-0.046*	0.001
	(0.026)	(0.022)	(0.022)	(0.026)	(0.026)	(0.029)	(0.026)	(0.022)
3. Medium CO2 tax	-0.064*	-0.066**	-0.068**	-0.054	-0.042	-0.043	-0.042	-0.009
	(0.032)	(0.032)	(0.033)	(0.032)	(0.032)	(0.030)	(0.026)	(0.024)
4. High CO2 tax	-0.075	-0.062	-0.060	-0.044	-0.040	-0.056	-0.067	-0.048
	(0.046)	(0.043)	(0.045)	(0.044)	(0.048)	(0.054)	(0.052)	(0.043)
Ln GDP per capita		0.166***	0.136**	0.147*	0.137	0.155	0.214**	0.273**
		(0.060)	(0.064)	(0.075)	(0.089)	(0.090)	(0.087)	(0.130)
Industry structure			0.005	-0.001	0.000	0.002	0.003	-0.001
			(0.006)	(0.004)	(0.004)	(0.005)	(0.005)	(0.007)
Import duty				-0.018	-0.001	0.006	0.014	0.001
				(0.014)	(0.018)	(0.020)	(0.024)	(0.017)
Real exchange rate					0.002*	0.002*	0.002*	0.001
					(0.001)	(0.001)	(0.001)	(0.001)
Ln CO2 intensity						-0.016	-0.119	-0.190
						(0.053)	(0.105)	(0.132)
Ln energy use							-0.176	0.052
							(0.118)	(0.130)
Environmental policy stringency								0.010
								(0.017)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.041**	-1.572**	-1.424**	-1.347*	-1.477*	-1.738**	-0.809	-3.039*
	(0.018)	(0.581)	(0.574)	(0.689)	(0.819)	(0.775)	(1.141)	(1.484)
Observations	720	720	720	600	528	461	461	399
R-squared	0.205	0.245	0.258	0.254	0.334	0.392	0.415	0.447
# of Countries	30	30	30	25	22	22	22	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In line with the literature, I also use net imports measured in value added as an alternative outcome variable. This variable was normalised by the country's GDP in order to deal with potential heteroskedasticity issues. The results are shown in table 11.

The coefficient of my explanatory variable, the lagged carbon tax rate is positive and significant in all models except model 8. The coefficient is 0.001 across the models. This implies that a $1 increase in the tax rate leads to an increase in the ratio of net imports to total GDP of 0.001, ceteris paribus. Alternatively, this means that on average, a 10% increase in the carbon tax rate would result in a 1.2%* increase in net imports in value added, ceteris paribus, which is economically significant.

As discussed earlier, this outcome variable is not as informative in indicating carbon leakage, as it does not capture the carbon content of the trade flows. Hence, these results indicate that leakage has occurred in economic terms, but this does not directly provide evidence for carbon leakage.

Table 11: FE regression of carbon tax on net imports in value added

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Net imports / GDP							
Lag of carbon tax rate	0.001**	0.001*	0.001*	0.001**	0.001*	0.001*	0.001*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Ln GDP per capita		-0.075**	-0.078**	-0.041	-0.024	0.003	0.003	0.021
		(0.029)	(0.034)	(0.025)	(0.037)	(0.037)	(0.046)	(0.054)
Industry structure			0.000	-0.005**	-0.005**	-0.005**	-0.005**	-0.008***
			(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Import duty				0.009	0.010	0.012	0.012	0.003
				(0.007)	(0.017)	(0.016)	(0.017)	(0.010)
Real exchange rate					-0.000	-0.000	-0.000	-0.001**
					(0.001)	(0.001)	(0.001)	(0.000)
Ln CO2 intensity						0.082***	0.082	0.082
						(0.027)	(0.061)	(0.085)
Ln energy use							0.000	0.160***
							(0.067)	(0.051)
Environmental policy stringency								0.023**
								(0.009)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.002	0.736**	0.751**	0.515*	0.364	0.020	0.020	-1.329**
	(0.009)	(0.282)	(0.299)	(0.250)	(0.341)	(0.345)	(0.450)	(0.616)
Observations	690	690	690	575	506	439	439	380
R-squared	0.316	0.346	0.346	0.395	0.337	0.339	0.339	0.476
# of Countries	30	30	30	25	22	22	22	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

*(10% of Mean tax rate x coefficient / Mean outcome variable) x 100%

iii) Robustness checks and sensitivity analysis

This section presents several alternative regressions to test the robustness of my results. Firstly, table 12 uses an alternative explanatory variable, namely the government revenue from carbon taxes. This variable was normalised by GDP to account for differences in economy sizes and lagged for a period of 1 year to incorporate the adjustment period businesses require to adapt to new regulations.

All models (except model 1) find a positive coefficient for the effect of government carbon tax revenue on net imports. However, none of these results are statistically significant. The statistically significant explanatory variables were the log of GDP per capita (model 1,3,4,5), industry structure (model 6,7,8), the real effective exchange rate (model 2,3,8), the log of energy use (model 8) and the environmental policy stringency index (model 8).

The statistically insignificant results for the explanatory variable suggest that, during the sample period, carbon taxes have not been a significant factor in explaining the rise in net imports of EU ETS countries. This result is in contrast with my earlier findings in table 8, but is in line with the literature. Reinaud (2008), Sartor (2013), Branger et al. (2016), Naegele & Zaklan (2019) and Verde (2020) all found insignificant results when regressing their respective explanatory variables on the net (CO2) imports of EU ETS countries. Therefore, these authors all concluded that carbon leakage has not been caused by the stringency of the environmental policy being investigated. Hence, based on this table, I may draw a similar conclusion, that carbon taxes have not caused carbon leakage within EU ETS countries in my sample period.

Table 12: FE Regression of lagged carbon tax revenue on net imports in embodied carbon and in value added

	Net embodied CO2 / Total CO2				Net imports / GDP			
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lag of Government tax revenue / GDP	-1.366	3.689	4.189	5.529	2.921	1.711	0.349	1.177
	(11.612)	(11.222)	(11.458)	(7.823)	(10.954)	(9.730)	(11.186)	(7.819)
Ln GDP per capita	0.118*	0.082	0.182**	0.250*	-0.084**	-0.015	0.028	0.046
	(0.067)	(0.092)	(0.084)	(0.131)	(0.035)	(0.038)	(0.042)	(0.049)
Industry structure	0.004	0.001	0.004	0.000	0.000	-0.005***	-0.005**	-0.008***
	(0.006)	(0.004)	(0.004)	(0.006)	(0.003)	(0.002)	(0.002)	(0.001)
Import duty		0.000	0.021	0.004		0.010	0.014	0.004
		(0.028)	(0.036)	(0.025)		(0.017)	(0.018)	(0.010)
Real exchange rate		0.002*	0.002**	0.001		-0.000	-0.000	-0.001***
		(0.001)	(0.001)	(0.001)		(0.001)	(0.001)	(0.000)
Ln CO2 intensity			-0.085	-0.149			0.048	0.026
			(0.114)	(0.157)			(0.057)	(0.060)
Ln energy use				0.072				0.160***
				(0.123)				(0.053)
Environmental policy stringency				0.012				0.023**
				(0.017)				(0.010)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.252*	-1.006	-0.480	-3.069**	0.815**	0.305	0.020	-1.329**
	(0.622)	(0.876)	(1.120)	(1.375)	(0.306)	(0.358)	0.117	-1.490**
							(0.443)	(0.631)
Observations	690	506	439	380	690	506		
R-squared	0.225	0.303	0.405	0.438	0.319	0.309	439	380
# of Countries	30	22	22	19	30	22	0.305	0.457

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Following the same procedure as table 10, I also construct a categorical variable based on the magnitude of the country's normalised carbon tax government revenues. Likewise, Group 1 includes countries without carbon tax revenue, Group 2 comprises of countries that have a low carbon tax revenue, Group 3 includes countries with a medium tax revenue and group 4 includes countries with a high tax revenue. Table 13 provides the results of the model.

Once again, the coefficients are mostly negative, suggesting that countries with carbon taxes have fewer net CO2 imports than countries without carbon taxes. In other words, carbon tax countries have lower carbon leakage rates that non-taxed countries, which contradicts my hypothesis. In contrast to the results in table 10, a higher tax category is associated with a decreasingly negative coefficient. This indicates that countries in the high tax rate group have more Net CO2 imports than countries in the lowest tax rate group. However, the only results that are statistically significant are from group 2 (Low tax revenue). Hence, the results must be interpreted with due caution.

Table 13: Regression of carbon tax revenue groups on net imports (in embodied carbon)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Net embodied CO2 / Total CO2							
2. Low CO2 tax revenue	-0.047*	-0.061**	-0.055**	-0.045*	-0.029	-0.023	-0.022	-0.003
	(0.023)	(0.024)	(0.025)	(0.023)	(0.031)	(0.026)	(0.022)	(0.024)
3. Medium CO2 tax revenue	-0.053	-0.052	-0.055	-0.039	-0.036	-0.015	-0.015	0.002
	(0.034)	(0.032)	(0.034)	(0.034)	(0.031)	(0.030)	(0.029)	(0.027)
4. High CO2 tax revenue	-0.017	-0.015	-0.013	-0.004	0.013	0.024	0.026	0.029
	(0.038)	(0.038)	(0.041)	(0.037)	(0.037)	(0.041)	(0.043)	(0.030)
Ln GDP per capita		0.163***	0.133**	0.144**	0.108	0.127	0.190**	0.255*
		(0.057)	(0.059)	(0.067)	(0.089)	(0.087)	(0.084)	(0.127)
Industry structure			0.005	-0.001	0.001	0.003	0.004	0.001
			(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.006)
Import duty				-0.016	-0.001	0.004	0.013	-0.001
				(0.014)	(0.019)	(0.020)	(0.025)	(0.018)
Real exchange rate					0.002*	0.002*	0.002*	0.001
					(0.001)	(0.001)	(0.001)	(0.001)
Ln CO2 intensity						0.003	-0.098	-0.132
						(0.050)	(0.116)	(0.156)
Ln energy use							-0.177	0.041
							(0.127)	(0.124)
Environmental policy stringency								0.010
								(0.018)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.035*	-1.555***	-1.401**	-1.331**	-1.233	-1.526*	-0.633	-2.866**
	(0.017)	(0.552)	(0.534)	(0.626)	(0.837)	(0.792)	(1.166)	(1.319)
Observations	720	720	720	600	528	461	461	399
R-squared	0.205	0.244	0.258	0.252	0.332	0.388	0.412	0.444
# of Countries	30	30	30	25	22	22	22	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Given that firms have an adjustment period to adapt to new regulations, I have incorporated lags of multiple years in table 14. The table includes tax rate lags of 1, 2, 3 and 5 years. The results are positive and statistically significant for all lag periods when all controls are included. The magnitude of the coefficient remains 0.001 across all models, indicating that the adjustment time does not affect the magnitude of carbon leakage.

Table 14: FE regressions with different lags of carbon tax rate on net embodied CO2 imports

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Net embodied CO2 / Total CO2							
Tax rate t-1	0.000	0.001**						
	(0.000)	(0.000)						
Tax rate t-2			0.000	0.001*				
			(0.000)	(0.000)				
Tax rate t-3					0.000	0.001*		
					(0.000)	(0.000)		
Tax rate t-5							0.001**	0.001
							(0.000)	(0.000)
Ln GDP per capita		0.195		0.238*		0.269**		0.329**
		(0.124)		(0.124)		(0.121)		(0.116)
Industry structure		0.002		0.001		0.001		-0.001
		(0.006)		(0.006)		(0.006)		(0.005)
Import duty		0.002		0.033		0.066*		0.090*
		(0.023)		(0.036)		(0.038)		(0.047)
Real exchange rate		0.002**		0.002**		0.002***		0.002***
		(0.001)		(0.001)		(0.001)		(0.001)
Ln CO2 intensity		-0.024		-0.102		-0.149		-0.193
		(0.158)		(0.159)		(0.136)		(0.114)
Ln energy use		0.071		0.054		0.026		-0.011
		(0.114)		(0.118)		(0.112)		(0.113)
Environmental policy stringency		0.012		0.013		0.013		0.014
		(0.017)		(0.018)		(0.018)		(0.016)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.001	-2.705**	-0.007	-2.971**	0.036*	-3.019***	0.052***	-3.273***
	(0.030)	(1.256)	(0.024)	(1.181)	(0.018)	(1.030)	(0.012)	(0.875)
Observations	690	380	660	361	630	342	570	304
R-squared	0.189	0.460	0.193	0.449	0.169	0.438	0.169	0.474
# of countries	30	19	30	19	30	19	30	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Using the approach by The World Bank (2008), I construct an alternative outcome variable by using the ratio of imports to exports, both in embodied carbon and in value added. Table 15 presents the result. In line with my main regression results, these robustness results show that the coefficient of the lagged carbon tax rate is positive and significant (except in model 8).

Table 15: FE Regression of lagged carbon tax on EU ETS countries' import-export ratio (in value added and in embodied carbon)

	CO2 imports / CO2 exports				Imports / Exports			
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lag of Carbon tax rate	0.002*	0.003***	0.002**	0.002*	0.002*	0.002*	0.002*	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Ln GDP per capita	0.307	0.268	0.468**	0.697**	-0.092	0.063	0.142	0.266
	(0.217)	(0.250)	(0.173)	(0.259)	(0.104)	(0.184)	(0.166)	(0.273)
Industry structure	-0.000	0.001	0.004	-0.004	-0.001	-0.008	-0.009**	-0.013***
	(0.007)	(0.006)	(0.007)	(0.011)	(0.005)	(0.005)	(0.004)	(0.004)
Import duty		-0.065	-0.012	0.010		0.051	0.054	0.042
		(0.058)	(0.047)	(0.043)		(0.055)	(0.054)	(0.038)
Real exchange rate		0.003**	0.004**	0.004**		-0.000	-0.000	-0.003
		(0.001)	(0.002)	(0.002)		(0.002)	(0.002)	(0.002)
Ln CO2 intensity			-0.250	-0.142			0.177	0.153
			(0.208)	(0.257)			(0.129)	(0.200)
Ln energy use				0.199				0.257*
				(0.188)				(0.142)
Environmental policy stringency				0.056				0.068**
				(0.050)				(0.028)
Country & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.877	-1.822	-1.326	-7.653***	1.962*	0.548	0.274	-3.425
	(2.130)	(2.535)	(2.838)	(2.496)	(0.983)	(1.784)	(1.776)	(2.820)
Observations	690	506	439	380	690	506	439	380
R-squared	0.196	0.303	0.383	0.465	0.279	0.233	0.279	0.340
# of Countries	30	22	22	19	30	22	22	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As a final test, I have constructed an instrumental variable for carbon taxation. Based on the endogeneity test in Appendix table 18, an Instrumental variable estimator is preferred over OLS due to the potential endogeneity of the carbon tax rate. As mentioned before, there may be confounding variables that influence both my outcome and explanatory variable, which can be isolated using an IV.

The instrument used for carbon tax rate is the average carbon tax rate of the border countries. This includes all countries within the sample dataset which share physical or nautical borders (i.e. UK and Netherlands are considered neighbours). The theory behind this is that policy decisions of neighbouring countries can influence domestic policies (Lumsdaine, 1996). Hence, it is argued that a higher average carbon tax of neighbouring countries influences the country to implement or increase its domestic carbon tax rate.

The conditions for an instrumental variable are: 1) relevance: that it must be strongly correlated with the explanatory variable (i.e., carbon tax), and 2) validity: uncorrelated with any other (unobserved) determinant of the outcome variable (i.e., net CO2 imports).

Regarding the relevance assumption, Appendix table 19 shows that the IV is positively correlated with the carbon tax rate, and that this coefficient is statistically significant at the 1% level. Moreover, Appendix table 20 shows that the F-statistic is greater than the rule of thumb (10), implying that the IV is relevant and strong.

However, it is likely that the IV does not satisfy the validity assumption. For example, Appendix table 21 shows that there is reverse causality of the carbon tax level on my IV, indicated by the positive and statistically significant coefficient. This suggests that the IV is not fully exogenous and may therefore be unable to present a causal effect for carbon tax rates on Net CO2 imports. Therefore, we must be careful when interpreting the results using the IV in table 16.

Table 16 presents the results of the effect of carbon tax rate on net CO2 imports, whereby carbon tax rate is instrumented by the average carbon tax rate of neighbouring countries. The coefficient of carbon tax level is negative and statistically significant. This implies that countries with a higher tax level have fewer net imports of embodied carbon, indicating less carbon leakage. This contrasts the main results from table 8. However, because the IV does not satisfy the validity assumption, I cannot conclude whether this effect is causal.

Table 16: Instrumental variable approach - carbon tax rate on net CO2 imports

VARIABLES	(1) netCO2imports
carbontaxlevel	-0.002***
	(0.001)
lngdp15	0.091***
	(0.014)
industry	-0.000
	(0.001)
tariffrevgdp	-0.019
	(0.013)
reexrate	0.004***
	(0.000)
lnCO2intensity	-0.438***
	(0.054)
lnenergyuse	-0.240***
	(0.025)
envstringency	-0.043***
	(0.017)
Country/Year FE	Yes
Constant	1.192***
	(0.173)
Observations	399
R-squared	0.479

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Conclusion

This paper has analysed whether the carbon taxes imposed by several EU ETS countries have caused carbon leakage. Carbon leakage is an important concern for policymakers in the context of environmental policy. If an environmental policy such as a carbon tax induces carbon leakage, then the reduction in domestic emissions may be offset by an increase in emissions abroad. This would significantly limit the true effectiveness of the policy in combatting global climate change.

My empirical analysis is based on the theory that carbon leakage can be measured through a change in net trade flows. This is especially true for net trade flows measured in their embodied carbon content, as this captures the displacement of CO2 emissions across countries. I used a dataset by the OECD, which provided CO2 embodied import and export data for 65 economies from 1995 to 2018. I combined this with World Bank carbon pricing data, which measures the rate and scope of carbon taxes in all countries. My measure of environmental stringency is a one-year lag of carbon tax rate. Using a similar methodology as previous literature, I adopt a fixed effects model to estimate the effect of carbon taxation on carbon leakage.

I find mixed results for the relationship between carbon taxes and carbon leakage, depending on how the variables are measured. When using the carbon tax rate as the explanatory variable, I find a positive and statistically significant relationship that is robust to different time lags and to different measures of carbon leakage. However, when using a categorical explanatory variable of different carbon tax rate groups, I find that countries with taxes have lower levels of carbon leakage compared to countries without the tax. This result contradicts with my hypothesis. Furthermore, using government revenues from carbon taxation as the explanatory variable, I find statistically insignificant results. This is in line with the literature and suggests that there is no evidence for carbon leakage. Given that there are inconsistencies in the results depending on the variables measured, further research is necessary in order to find causal evidence.

Given that the magnitudes are relatively small, both for the positive and negative coefficients, I can conclude that carbon tax rates have little effect on carbon leakage. If carbon leakage effects would have been strong, then the results would have consistently indicated the same relationship of carbon tax on net CO2 imports. This finding is in line with the literature, which find little to no evidence for carbon leakage.

The finding that carbon taxes seem to have little effect on carbon leakage is valuable to policymakers considering implementing environmental policies. This is because it implies that the concerns about carbon leakage are not well-substantiated. Policymakers looking to introduce carbon taxes should therefore not be too fearful of firms threatening to offshore their emission-intensive production activities abroad.

Having said that, the carbon border adjustment mechanism (CBAM) will be an effective policy tool to help level the playing field between EU and non-EU firms. Even though current carbon tax rates do not have a large effect on carbon leakage, it is not guaranteed that this will also be the case in the future as environmental policies become more stringent.

There are several limitations of this paper, which means that the results must be interpreted with due caution. Firstly, this paper is limited to multilateral trade flows. This means that it is not possible to identify the specific trading partners of the countries in my sample. Therefore, some important determinants of trade flows could not be measured, such as geographical distance, common language use, or transportation costs between country A and B. Hence, some important control variables were not included which may bias the coefficients of my explanatory variable. To resolve this, a dataset must be constructed using input-output tables to identify the bilateral trade flows between each country. Secondly, this paper has analysed net trade flows at the national level, instead of looking at specific sectors. Most of the literature choose to analyse the net trade flows in specific (emission-intensive) sectors, such as manufacturing or steel, as this provides a more in-depth picture of carbon leakage in that specific sector. My results may be distorted due to different net trade flows in different sectors. For the same reason, I cannot determine which specific carbon leakage channel caused the carbon leakage. The OECD dataset provides carbon embodied trade flows at the sector level so this could be explored in further research. Thirdly, some of my variables may suffer from an endogeneity problem, which may have resulted in biased estimators. For example, my measure of trade barriers - revenue from custom import duties – may be dependent on the net level of imports. Lastly, this analysis also has some concerns regarding external validity. The paper analyses the carbon tax effect in EU ETS countries and therefore the results are not necessarily applicable to countries outside the EU ETS. Moreover, the paper covers the time period up to 2018. The COVID-19 pandemic and War in Ukraine has significantly distorted net trade flows, which may lead to different results for the subsequent years.

Future research should look at addressing the limitations of this paper. This includes using bilateral trade flows instead of multilateral trade flows, focusing on the effect of carbon taxes in specific (emission-intensive) sectors, use alternative control variables that have less endogeneity issues and use more recent time periods to investigate how the rising carbon taxes are affecting carbon leakage.

6. References

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7. Appendix

Figure 9: Hausman Test

Hausman (1978) specification test

	Coef.
Chi-square test value	73.419
P-value	0

P-value < 0.05 significance level

The null hypothesis is that the preferred model is random effects
The alternate hypothesis is that the model is fixed effects

Since the P Value < 0.05; H0 is rejected, implying that random effects assumption is false. Hence, Fixed Effects model is used.

Figure 10: BP Lagrangian Multiplier Test

```
Breusch and Pagan Lagrangian multiplier test for random effects

        netco2imports[CountryNumber,t] = Xb + u[CountryNumber] + e[CountryNumber,t]

        Estimated results:
                         |       Var     SD = sqrt(Var)
                ---------+-----------------------------
                netco2i~s |   .0194348       .1394088
                        e |   .0024488       .0494854
                        u |   .0063592       .0797445

        Test: Var(u) = 0
                             chibar2(01) =   1179.73
                          Prob > chibar2 =    0.0000
```

P-value < 0.05 significance level

The null hypothesis is that the preferred model is (pooled) OLS

Since the P value < 0.05; H0 is rejected, implying that the Pooled OLS model is rejected

Figure 11: Modified Wald Test for Heteroskedasticity

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (19)  =    1975.95
Prob>chi2 =      0.0000
```

P-value < 0.05 significance level

Null hypothesis is that the model is homoscedastic
Alternative hypothesis is that the model is heteroskedastic

The null hypothesis of homoskedasticity can be rejected. Hence, the model has a heteroskedasticity problem. Since this is the case, I use robust standard error for my fixed effects model.

Table 17: List of countries

#	Country name	Country code	#	Country name	Country code
1	Austria	AUT	16	Italy	ITA
2	Bulgaria	BGR	17	Latvia	LVA
3	Belgium	BEL	18	Lithuania	LTU
4	Croatia	HRV	19	Luxembourg	LUX
5	Cyprus	CYP	20	Malta	MLT
6	Czech-Republic	CZE	21	Netherlands	NLD
7	Denmark	DNK	22	Norway	NOR
8	Estonia	EST	23	Poland	POL
9	Finland	FIN	24	Portugal	PRT
10	France	FRA	25	Romania	ROU
11	Germany	DEU	26	Slovakia	SVK
12	Greece	GRC	27	Slovenia	SVN
13	Hungary	HUN	28	Spain	ESP
14	Iceland	ISL	29	Sweden	SWE
15	Ireland	IRL	30	United Kingdom	GBR

Table 18: Endogeneity test

```
estat endogenous

Tests of endogeneity
H0: Variables are exogenous

Robust score chi2(1)          =  22.7752  (p = 0.0000)
Robust regression F(1,369)    =  16.6528  (p = 0.0001)
```

P value < 0.05 significance level

We reject the null hypothesis that the variables are exogenous

Hence, we conclude that the carbon tax level is endogenous, hence we must use an IV estimator

Table 19: IV first stage regression

VARIABLES	(1) Carbon tax level
Average border country tax (IV)	0.428***
	(0.076)
Ln GDP per capita	35.149*
	(18.401)
Industry structure	-1.342***
	(0.385)
Import duty	0.247
	(2.373)
Real exchange rate	-0.439
	(0.290)
Ln CO2 intensity	-85.289**
	(43.286)
Ln energy use	-32.510
	(26.934)
Environmental policy stringency	-0.382
	(2.112)
Constant	67.688
	(159.765)
Country & Year FE	Yes
Observations	399
Number of countries	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 20: First stage F-test

```
estat firststage

First-stage regression summary statistics
```

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	Robust F(1,370)	Prob > F
carbontaxl~l	0.6176	0.5886	0.1971	87.0941	0.0000

Rule of thumb: F statistic > 10 → Strong instrument

Since 87.09 > 10, this means my instrument is a strong instrument

Table 21: Reverse causality test

VARIABLES	(1) Average carbon border tax
carbontaxlevel	0.343*
	(0.184)
Ln GDP per capita	-21.577
	(16.002)
Industry structure	1.745
	(1.201)
Import duty	1.683
	(2.327)
Real exchange rate	-0.034
	(0.117)
Ln CO2 intensity	-1.742
	(21.215)
Ln energy use	34.587
	(26.215)
Environmental policy stringency	1.189
	(4.100)
Constant	-106.504
	(151.465)
Country & Year FE	Yes
Observations	399
Number of Countries	19

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1