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Does Carbon Pricing Affect International Competitiveness? Implications for Carbon Leakage

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Abstract

This study explores the impacts of carbon pricing on the international competitiveness of manufacturing sectors. A simple theoretical framework is developed to examine the link between carbon pricing and the market share of imported goods that may potentially lead to carbon leakage. We analyze the direct and indirect impacts by considering the shift from domestic to foreign inputs in the production of output goods. Using the European Union Emissions Trading System as an empirical setting, we estimate the effects of carbon pricing on imports and total value in both targeted and non-targeted sectors. The analysis of bilateral trade flows reveals that unilateral carbon pricing slightly weakens the competitiveness of the importing country in the target sector markets, potentially increasing the risk of carbon leakage. Conversely, the policy does not affect competitiveness in non-targeted sectors. The results suggest that unilateral carbon pricing directly influences the targeted sectors, but no evidence exists of spillover effects on non-targeted sectors.

Keywords: Carbon pricing, Competitiveness, Carbon leakage, Trade
JEL Classification Numbers: Q56, Q54, H23, F18

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1 Introduction

Various countries have introduced carbon pricing as a strategy to mitigate climate change. As of 2024, over 40 countries have adopted Emissions Trading Systems (ETS) and/or carbon taxes (World Bank, 2024). Alongside these policies, there is growing concern about their impacts on competitiveness and carbon leakage. Awareness of these carbon pricing issues has motivated the EU to introduce the Carbon Border Adjustment Mechanism (CBAM), which aims to impose a fair price on the carbon emissions of carbon-intensive goods imported into the EU. Although several researchers have explored the impacts of carbon pricing policies on competitiveness and/or carbon leakage in targeted sectors, they are yet to reach a consensus on whether the impacts are sufficiently significant to warrant countermeasures. This study explores how carbon pricing influences competitiveness and carbon leakage. We address this central question by constructing a simple theoretical framework for international trade and empirically investigating the impact on two factors.

Loss of competitiveness and carbon leakage are two major concerns when carbon pricing is implemented. Completely assessing the consequences of carbon pricing is difficult without simultaneously considering both issues because they are closely connected. When carbon pricing is introduced in a country, its international competitiveness may weaken due to increased consumption of goods from countries without such regulations. This shift in market competitiveness can lead to carbon leakage. However, detailed data on carbon leakage are often lacking due to measurement difficulties.[1] To address this issue, we develop a theoretical framework that allows us to analyze the impact of carbon pricing on carbon leakage using available data on international competitiveness. In other words, we examine the risk of carbon leakage by assessing how carbon pricing influences a measure of competitiveness.

We extend the literature on competitiveness and carbon leakage by considering whether a sector is directly targeted by carbon pricing. Most carbon pricing worldwide targets sectors mainly producing intermediate goods that are used in other sectors as inputs. Therefore, we define sectors subject to carbon pricing as *input sectors* and non-targeted sectors as *output sectors*. Building on this definition, we investigate not only the direct effects of carbon pricing on input sectors but also its indirect effects on output sectors. Indirect effects may arise due to price changes in input sectors, which can, in turn, impact output sectors through production linkages. A comprehensive understanding of these effects is crucial for policymakers to avoid

[1] For example, Naegele and Zaklan (2019) and Aichele and Felbermayr (2015) explore carbon leakage using country-by-sector data, but their datasets cover at most 13 time points. Eskander and Fankhauser (2023) compiles emission data spanning 23 years, but only at the country level not the country-by-sector level. Misch and Wingender (2024) examine the impact on carbon leakage using OECD data at the country-by-sector level, covering both direct carbon emissions and carbon embodied in goods and services. However, this detailed dataset also has a shorter time span, covering only 11 years.

unintended negative consequences and enhance the effectiveness of carbon pricing.

To answer our key research question, we use the EU ETS as a case study for carbon pricing. Since its launch in 2005, the EU ETS has aimed to reduce greenhouse gas (GHG) emissions by requiring certain plants in carbon-intensive sectors to pay for emissions that exceed their allowances. This policy has three essential features that make it suitable for our research. First, the EU ETS primarily targets sectors that predominantly produce intermediate goods that are often used in other sectors.[2] This characteristic allows us to estimate the indirect effects on the output sectors, as carbon pricing in one sector can influence other industries through supply chains. Second, the carbon price in EU countries is generally higher than in most other countries.[3] This alleviates the concern that carbon pricing in other countries may distort the estimated impact of the EU ETS. Third, the availability of long-term data allows us to examine trends before and after implementing the EU ETS. Trade data sources, such as the OECD and UN Comtrade typically provide records dating back to the mid-1990s. Since the EU ETS was introduced in 2005, we can collect approximately 10 years of data before and 15 years after its implementation, ensuring a robust analysis.

Our empirical strategy is guided by a simple theoretical framework for bilateral trade that illustrates how carbon pricing may affect competitiveness and increase the risk of carbon leakage. The framework assumes that only the importing country implements carbon pricing, while the exporting country does not. We focus on the markets of a sector in an importing country. First, regarding the competitiveness of input sectors, our model shows that the importing country's market share declines, suggesting a potential loss in competitiveness. This may occur because the cost of carbon pricing is passed on to domestic prices, shifting demand from domestically produced goods to imported alternatives. Second, the risk of carbon leakage in the input sectors is likely to rise owing to the demand shift mentioned above. This expectation follows from our assumption that only the importing country imposes carbon pricing, implying that the goods produced in that country emit fewer GHGs than those produced by the exporting country. Finally, the effects on the competitiveness and carbon leakage of output sectors depend on whether these sectors primarily produce intermediate or final goods. The variation in these impacts can be attributed to differences in substitution potential among sectors.

This study examines the impacts of carbon pricing using three empirical methodologies.

[2]The sectors targeted by the EU ETS in Phase 1 include power stations and other combustion plants, oil refineries, coke ovens, iron and steel plants, cement clinker, glass, lime, bricks, ceramics, pulp, and paper and board. In Phases 2 and 3, additional sectors such as aviation, aluminum, and petrochemicals were included (Climate Action, 2015).

[3]According to data from World Bank (2024), as of April 1, 2024, only Finland, Liechtenstein, Norway, Sweden, and Switzerland have carbon taxes higher than the EU ETS among the 33 national carbon taxes or ETS worldwide. However, Liechtenstein and Norway are not included in our dataset.

First, we employ a difference-in-differences (DiD) design to identify the causal impacts of carbon pricing on competitiveness and carbon leakage. Second, we use the Poisson pseudo-maximum likelihood (PPML) method (Silva and Tenreyro, 2006). As our analysis applies the gravity model to assess the effects of carbon pricing on trade settings, PPML is particularly suitable for our research. It offers two key advantages: (i) it robustly handles zero trade volumes and (ii) it aligns with the gravity model, which is commonly used to assess trade impacts. To implement both DiD and PPML, we construct a dummy variable based on the differences in EU ETS status between the importing and exporting countries, following Aichele and Felbermayr (2015). A recent PPML methodology grounded in the gravity model requires multiple fixed effects (FEs) such as importer- and exporter-year FE. However, this requirement complicates the measurement of the DiD estimator in the case of country-specific policies, as these effects tend to be absorbed by country-year FE in the PPML framework. To address this issue, we introduce a dummy variable that captures the importer-exporter-year status difference in the policy. Third, we apply an instrumental variable (IV) approach, specifically nonlinear two-stage least squares (N2SLS). We use a dummy variable related to carbon pricing as an IV for price changes in the input sectors within the importing country due to the policy.[4] This approach enables us to capture the indirect effects of carbon pricing on the output sectors through its impacts on the input sectors.

This study's findings can be summarized as follows. First, unilateral carbon pricing weakens the competitiveness of the input sectors in the importing country. In the case of the EU ETS, its introduction led to a 36% increase in the import value for the importing country with the policy, indicating a decline in its domestic market share. This loss of competitiveness results from trade reallocation in which goods previously sourced domestically from countries with carbon pricing are replaced with imports from those without. Second, unilateral carbon pricing does not affect the competitiveness of the output sectors, regardless of whether they primarily produce intermediate or final goods. This finding contradicts our theoretical framework's prediction. A possible explanation is that the share of input quantity from carbon-priced sectors relative to the total input quantity from output sectors is typically small. Third, the impacts of carbon pricing on carbon leakage depends on demand shifts in the input sectors. Carbon leakage is likely to occur in the input sectors as carbon pricing shifts demand from domestically produced goods to imports. However, no carbon leakage is expected in the output sectors, because their demand remains unchanged. Finally, government protection in certain sectors can mitigate the negative impacts of carbon pricing.

This study contributes to existing literature in several ways. First, although various studies on carbon pricing have examined its impacts on competitiveness and/or carbon leakage,

[4]In Section 4.2, we further discuss the IV strategy. In the first stage of the IV estimation, we use the import value of the input sectors as the dependent variable instead of the price change.

most have focused only on the direct effects on targeted input sectors (e.g., Aichele and Felbermayr, 2015; Anger and Oberndorfer, 2008; Chan et al., 2013; Demailly and Quirion, 2008; He and Chen, 2023; Naegele and Zaklan, 2019; Petrick and Wagner, 2014; Qi et al., 2021; Sadayuki and Arimura, 2021). Little attention has been paid to the indirect effects on non-targeted output sectors, despite the possibility that changes in input sectors due to carbon pricing may influence output sectors. For instance, Feenstra (1998) and Grossman and Rossi-Hansberg (2008) imply that policy-induced cost changes in input sectors can alter the production conditions, such as cost structures, in output sectors potentially affecting their competitiveness. To the best of our knowledge, this study is the first to analyze both the direct and indirect effects in a step-by-step manner, explicitly considering the relationship between the input and output sectors.

Second, by examining the long-term global dynamics of carbon pricing, we contribute to the literature on the effects of environmental regulations on competitiveness and carbon leakage. While many studies explore this topic, most rely on firm-level data from a single country or region comprising closely linked economies, such as the EU (see Verde (2020) for a summary of the associated literature). These studies primarily capture changes at national or regional levels. Only a few studies, such as Aichele and Felbermayr (2015) and Naegele and Zaklan (2019), have investigated the global effects of environmental regulations, with their analysis periods limited to a maximum of three and 13 years, respectively. To provide deeper insight into the long-term dynamics of environmental regulations, we conduct an analysis using global data spanning 26 years.

Finally, we extend the literature on carbon leakage in terms of its measurement. Identifying carbon leakage and inferring the causal impacts of policy on emissions requires extensive data (Verde, 2020). Previous studies have attempted to empirically assess carbon leakage (e.g., Aichele and Felbermayr, 2015; Dechezleprêtre et al., 2022; Eskander and Fankhauser, 2023; Misch and Wingender, 2024; Naegele and Zaklan, 2019). However, the lack of suitable detailed data poses a significant challenge for both identifying and measuring emissions (Martin et al., 2014). To address this issue, we develop a concise theoretical framework that links changes in prices and quantities. This approach has two primary advantages. First, it provides novel insights into the risk of carbon leakage, even when data availability is limited. Second, it enables us to assess the indirect impacts of changes in targeted input markets on carbon leakage in non-targeted output markets.

The remainder of this paper is structured as follows. Section 2 provides an overview of carbon pricing policies and defines competitiveness and carbon leakage. Section 3 constructs a theoretical framework to examine how carbon pricing influences competitiveness and carbon leakage risk and derives expectations for the results. Section 4 outlines the empirical strategies and details of the data. Section 5 presents the empirical results and robustness checks.

Finally, Section 6 concludes the paper with a discussion of the findings.

2 Background

2.1 Carbon Pricing Policy

Carbon pricing is a policy instrument that requires emitters to pay for the external costs of GHG emissions. Various types of carbon pricing, including the ETS and carbon taxes, exist as explicit instruments, and fuel taxes exist as implicit instruments.[5] Although these mechanisms differ in their processes and characteristics, their implementation generally leads to an increase in the cost of producing goods in the targeted sectors. Green (2021) notes that, in the case of carbon taxes, the price of carbon is typically set by the government, whereas for the ETS, the total allowable GHG emissions for regulated entities are determined. In this sense, carbon taxes inherently have the potential to increase production costs, which may be passed on to consumer prices. Conversely, the ETS does not necessarily exhibit this characteristic. However, several sectors can pass on carbon costs to consumers following the introduction of the ETS, even when sufficient emission allowances are assigned to producers (Branger et al., 2016). For example, in manufacturing, the cost pass-through rate due to the ETS has been estimated to be 30–40% for ceramic bricks, over 100% for ceramic goods (Oberndorfer et al., 2010), and more than 100% for iron and steel (de Bruyn et al., 2010). The ability to pass on costs enables producers to avoid paying the full carbon costs (Arlinghaus, 2015), which can lead to windfall profits (Cludius et al., 2020; Joltreau and Sommerfeld, 2019). In summary, both the ETS and carbon taxes can affect production costs and lead to higher consumer prices. By focusing on price changes, this study explores the common impacts of various types of carbon pricing and examines these effects using a unified theoretical framework.

2.2 International Competitiveness and Carbon Leakage

Competitiveness is generally defined as a company's or sector's ability to thrive and develop in terms of market share, profits, or productivity (Dechezleprêtre and Sato, 2017). This study uses market share as a measure of international competitiveness and examines its relationship with carbon leakage. This measure is adopted for several reasons. First, as this study aims to explore global trade dynamics, data on competitiveness are limited. However, the market share of imported goods can be derived from trade-flow values, which are relatively easy to obtain. Second, market share is a suitable indicator for directly assessing the link between

[5] Explicit carbon pricing refers to instruments that directly set a price on GHG emissions, while implicit carbon pricing refers to instruments that indirectly set a price on GHG emissions by imposing costs on emission-related factors.

competitiveness and carbon leakage. As market share reflects whether domestic goods are preferred over imported goods, it captures shifts in the demand for products from different countries. In the context of carbon pricing, this shift in demand may lead to a shift from goods produced in countries with stricter emission regulations to those produced in countries with more lenient policies, resulting in the relocation of GHG emissions and carbon leakage.[6]

3 Theoretical Framework

3.1 Primitive Settings

We develop a simple theoretical framework for bilateral sector-level trade, focusing on price and quantity changes. Two countries—importing country j and exporting country i—engage in trade independently of other countries, with transactions occurring exclusively within a given sector.[7] Notably, we assume that all factors that may affect trade flows remain unchanged except for carbon pricing. This assumption allows us to treat the prices of imported goods as constant over time ($\overline{p_i}$). Additionally, we assume one-sided carbon pricing, meaning that only the importing country implements carbon pricing[8] and focus on the importing country's market when evaluating the effects of unilateral carbon pricing.[9]

3.2 Markets of Input Sectors

Before the implementation of carbon pricing, the total value consumed in the market of the importing country j is given by the sum of import and domestic values, expressed as:

$$p_{ij0}q_{ij0} = \overline{p_i}q_{i0} + p_{j0}q_{j0}, \tag{1}$$

where p and q denote the price and quantity of goods in a given input sector, respectively. $\overline{p_i}q_{i0}$ denotes the import value of goods produced in country i and consumed in country j,

[6] Carbon leakage occurs through several channels, such as changes in the international fossil fuel market, production, and market share (more details in Beck et al. (2023) and Naegele and Zaklan (2019)). This study focuses on the last channel.

[7] Although trade may extend beyond the sectoral boundaries, our data mitigate the concern. The sectoral classification we use (two-digit divisions of the International Standard Industrial Classification (ISIC) Rev.4) encompasses a broad range of similar industries. Thus, trade is considered to occur within a sector.

[8] The assumption of one-sided carbon pricing reflects real-world conditions, as it considers the relative difference in policy stringency between two countries by treating the less stringent carbon pricing as the baseline.

[9] Focusing on the importing country's market is useful for investigating the indirect impacts on output sectors, as it allows us to partially disregard confounding factors such as the effects of the importing country's carbon pricing on the exporting country.

while $p_{j0}q_{j0}$ represents the domestic value produced and consumed in country j. Note that the notation for the input sector is omitted because the same formulation applies across all sectors. Following the introduction of carbon pricing, the input price in country j will rise due to the pass-through cost of carbon pricing ($p_{j0} < p_{j1}$) (see Arlinghaus (2015) for a summary of the cost pass-through effects induced by carbon pricing). Consequently, the total value and resulting change in market share can be expressed as follows:

$$p_{ij1}q_{ij1} = \overline{p_i}q_{i1} + p_{j1}q_{j1}, \tag{2}$$

$$\begin{aligned}\Delta MS_{ij} \equiv \frac{p_{j1}q_{j1}}{p_{ij1}q_{ij1}} - \frac{p_{j0}q_{j0}}{p_{ij0}q_{ij0}} &= \left(1 - \frac{\overline{p_i}q_{i1}}{p_{ij1}q_{ij1}}\right) - \left(1 - \frac{\overline{p_i}q_{i0}}{p_{ij0}q_{ij0}}\right) \\ &= \frac{\overline{p_i}q_{i0}}{p_{ij0}q_{ij0}} - \frac{\overline{p_i}q_{i1}}{p_{ij1}q_{ij1}}.\end{aligned} \tag{3}$$

If goods from this sector are normal goods,[10] the domestic quantity declines from q_{j0} to q_{j1}, including the case of $q_{j0} = q_{j1}$ (i.e., no change).[11] Thus, given the decrease in domestic quantity and the assumption of a constant export price ($\overline{p_i}$), the import value would not decrease, but either remain unchanged or increase. To predict changes in market share, we require information on the direction of change in total value. At this stage, we can only predict an increase in the import value. By introducing an additional assumption that the total value remains constant over time ($\overline{p_{ij}q_{ij}} \equiv p_{ij0}q_{ij0} = p_{ij1}q_{ij1}$),[12] we can further anticipate changes in market share as follows.

$$\Delta MS_{ij} = \frac{\overline{p_i}(q_{i0} - q_{i1})}{\overline{p_{ij}q_{ij}}} \leq 0. \tag{4}$$

Considering that the import value increases while the total value remains unchanged, the market share of domestic goods necessarily declines. To summarize the predictions of our theoretical framework, we formulate the following hypothesis regarding the competitiveness of input sectors.

Hypothesis I-a. Carbon pricing decreases the market share of importing countries that implement the policy, thereby diminishing their competitiveness.

Furthermore, an expectation regarding carbon leakage can be established. In this framework, the importing country implements carbon pricing, but the exporting country does not. This

[10]In the empirical analysis, we consider the "Other Non-Metallic Mineral Products" and "Basic Metals" divisions of ISIC Rev.4 as input sectors, including iron, steel, cement, and aluminum. The goods in these sectors can be considered as normal goods.

[11]Even if the price elasticity of a good is very small, a decrease in the domestic quantity is induced under the normal good assumption, although the magnitude of the change may be small.

[12]We confirm this assumption's validity in Section 5.

suggests that the embodied carbon emissions in goods produced by the importing country are likely to be lower than those of the exporting country. Consequently, if demand shifts from the importing country to the exporting country, the likelihood of carbon leakage increases. Based on this discussion, we hypothesize the following regarding carbon leakage in the input sectors.

Hypothesis I-b. An increase in the import value exacerbates the risk of carbon leakage by shifting demand from the importing country to the exporting country.

3.3 Markets of Output Sectors

Findings from studies on global supply chains suggest that carbon pricing may affect output sector markets.[13] Feenstra (1998) and Grossman and Rossi-Hansberg (2008) imply that cost variations in input sectors can influence output sectors through changes in production costs, potentially altering the competitiveness in output sector markets. Before implementing carbon pricing, the domestic value of the importing country's output sectors is given by $p_{j0}^{Out}q_{j0}^{Out}$. After the policy is introduced, if domestic producers in the output sectors do not pass on the increased input costs resulting from carbon pricing to the output price, then the domestic value of the output sector remains unchanged. Conversely, if producers transfer higher input costs to output prices, domestic consumption in the importing country declines, leading to the substitution of domestic goods with imported alternatives. Given that the Armington elasticity of intermediate goods is lower than that of final goods (Saito, 2004), the first mechanism is more frequently observed in sectors where goods are primarily consumed as final goods because they face a higher risk of substitution by imports. Conversely, the second mechanism is more prevalent in sectors where goods are consumed as intermediate goods, as the likelihood of substitution is lower. Building on the above, we propose the following hypotheses regarding competitiveness and carbon leakage in the output sector markets.

If goods in the output sectors are primarily consumed as final goods:
Hypothesis II-a. Carbon pricing does not impact the market share of the importing country implementing the policy, meaning that its competitiveness remains unchanged.
Hypothesis II-b. The risk of carbon leakage does not increase because carbon pricing does not impact the market share of output goods in the importing country.

[13]This study disregards the effects of cost changes induced by carbon pricing in importing countries on the output sectors of exporting countries. The market share of foreign goods is minimal—averaging less than 2%—in the countries analyzed. Therefore, we assume that the carbon pricing policies of other countries only have a negligible influence on the domestic conditions of the output sectors.

If goods in the output sectors are primarily consumed as intermediate goods:

Hypothesis III-a. Carbon pricing slightly reduces the market share of the importing country implementing the policy, indicating a potential loss of its competitiveness.

Hypothesis III-b. An increase in import values in the output sectors can increase the risk of carbon leakage by shifting demand from the importing country to the exporting country.

Fig. 1 summarizes the theoretical framework for the market of input and output sectors. The producer in the targeted sector passes on the carbon costs to the price of goods (①). This price increase leads to a shift in demand within the input sector market from the importing country with carbon pricing to the exporting country without it, potentially increasing the risk of carbon leakage (②). The lower part of Fig. 1 illustrates the mechanisms through which cost changes in the input sector affect output sector markets. In final goods markets, carbon pricing is unlikely to induce a demand shift, thereby suppressing the risk of carbon leakage (③). Conversely, in intermediate goods markets, the policy reduces demand in the importing country, increasing its likelihood (③').

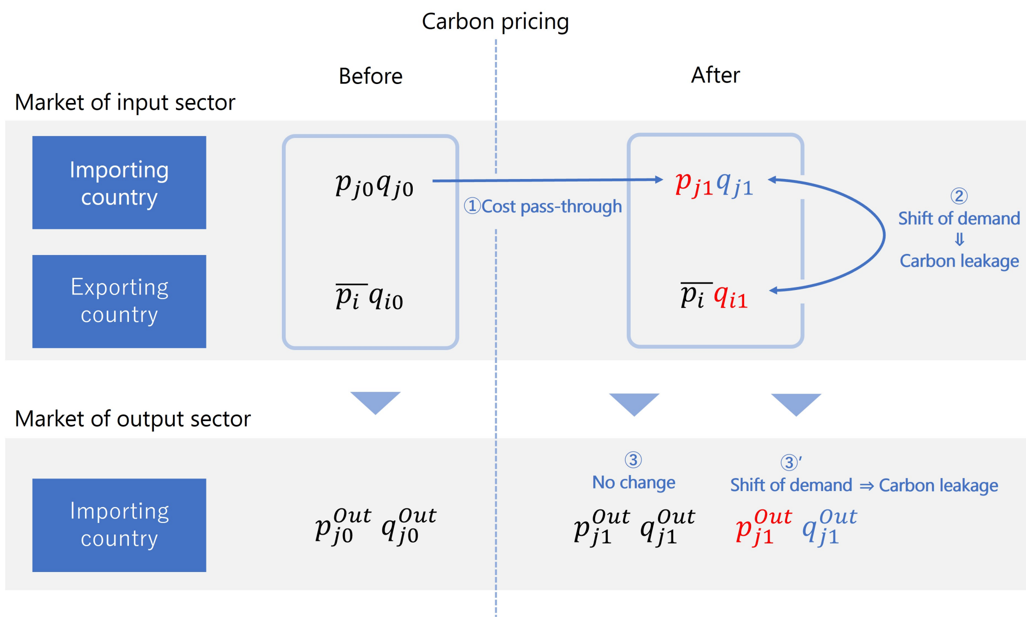


Fig. 1. Theoretical Framework

Notes: This figure illustrates the mechanism through which carbon pricing affects the markets of the importing country implementing the policy, helping anticipate its impacts on competitiveness and the risk of carbon leakage. The upper part of the figure depicts changes in the price and quantity of goods in input sectors, while the lower part shows the corresponding changes in output sectors. Red variable indicates an increase in price or quantity, while blue one denotes a decrease.

4 Empirical Strategies and Data

4.1 Specification

We present econometric specifications to analyze the direct effects of the EU ETS on the input sector markets and the indirect effects on the output sector markets. Although this study examines the effects of global dynamics using trade data, the theoretical framework developed in Section 3 does not sufficiently consider important trade structures, such as multilateral resistance terms. To address this limitation, we incorporate a gravity model into our empirical specifications by employing PPML (Silva and Tenreyro, 2006). We aim to capture the changes in the primary variable of interest, market share, which is defined as the ratio of the importing country's domestic value to its total value. Based on our theoretical framework, we can restate the market share as one minus the ratio of import value to total value. This formulation is more suitable for the gravity model, as the import value is more directly related to trade dynamics than the domestic value.

Direct impacts on markets of input sectors. To investigate this direct impact, we estimate the following model.

$$V_{ijst}^{In} = exp\left[\beta_0 + \beta_1 EUETS_{ijt} + \beta_2 jointFTA_{ijt} + \beta_3 jointCP_{ijt} + FEs + \epsilon_{ijst}\right], \qquad \textbf{(5)}$$

where the dependent variable V_{ijst}^{In} represents the import value ($Import_{ijst}^{In}$) or total value ($Total_{ijst}^{In}$) of goods in input sector s from exporting country i to importing country j in year t. We do not use market share itself as the dependent variable, since PPML examines count data rather than relative values such as shares. Following Aichele and Felbermayr (2015), we construct the key explanatory variable $EUETS_{ijt}$, which equals one if the status of the EU ETS introduction differs between the importing and exporting countries, and zero otherwise.[14] For example, if the importing country is an EU member and the exporting country is a non-EU country,[15] only the importing country is subject to the EU ETS. In this case, $EUETS_{ijt}$ takes the value of one if the importing and exporting countries have different conditions. Conversely, if both countries in the exporter-importer pair belong to the EU ETS or both do not, they share the same condition, and $EUETS_{ijt}$ takes the value of zero. The

[14]Unlike Aichele and Felbermayr (2015), we do not consider $EUETS_{ijt} = -1$, where only the exporting country is joining the EU ETS, to obtain clear results regarding the impacts of the EU ETS on import dynamics.

[15]In practice, the EU ETS has also been implemented outside the EU, such as Norway, Iceland, and Liechtenstein. In this study, these countries are excluded during data processing. Norway and Iceland are omitted for simplicity (details are in Section 4.3), and Liechtenstein is not included in the original data. Hence, the case of the EU ETS outside the EU is discarded here.

variables $jointFTA_{ijt}$ and $jointCP_{ijt}$ are dummy variables used to control for trade-related policies. They take the value of one if both countries i and j adopt free trade agreements (FTA) or carbon pricing policies (ETS or carbon taxes), respectively, and zero otherwise. Notably, $jointCP_{ijt}$ does not require importing and exporting countries to have the same carbon pricing system; rather, it focuses solely on whether both countries are subject to any form of carbon pricing. This allows us to control for the effects of virtual bilateral carbon pricing, which is a subject of growing importance among policymakers. Additionally, $jointFTA_{ijt}$ helps capture the level of economic integration between the two countries. The specification includes FEs that account for multiple factors, including year, importer-year, exporter-year, input sector-year, country pair, and country pair-input sector FEs, based on the gravity model. The error term is denoted by ϵ_{ijst}.

Indirect impacts on markets of output sectors. We examine the indirect impacts of the EU ETS on the market share in the output sectors using the following model.

$$V_{ijkt}^{Out} = exp\left[\gamma_0 + \sum_{y=-10}^{15} \gamma_{1,y} ln\ \widehat{Import_{ijs,t+y}^{In}} + \gamma_2 jointFTA_{ijt} + \gamma_3 jointCP_{ijt} + FEs + \epsilon_{ijkt}\right]. \quad \textbf{(6)}$$

Similarly to the direct-effect model, the dependent variable V_{ijkt}^{Out} represents the import value ($Import_{ijkt}^{Out}$) or total value ($Total_{ijkt}^{Out}$) of goods in an output sector k. The key distinction from equation 5 lies in the explanatory variables. Instead of the EU ETS dummy variable, we use the logarithm of the fitted import value of the input sector ($ln\ \widehat{Import_{ijs,t+y}^{In}}$) with year leads and lags ($y \in [-10, 15]$). The fitted import value is derived from equation 5 using $EUETS_{ijt}$ as an IV for equation 6. The validity of employing $ln\ \widehat{Import_{ijs,t+y}^{In}}$ as a measure to detect indirect effects is discussed in the following subsection. We use the same FEs as in the direct-effects model, except that the input sector-year and country pair-input sector FEs are replaced with the output sector-year and country pair-output sector FEs.

4.2 Identification

To examine the indirect impacts of the EU ETS on the markets of the output sectors through changes in those of the input sectors, we must measure the changes in input costs or quantities induced by the policy. However, due to the lack of precise data on the cost pass-through rate, we are unable to directly capture these changes. According to the theoretical framework discussed earlier, an increase in input costs caused by carbon pricing leads to an increase in the quantity of imported goods. This suggests that the directions of changes in input sector costs and import value in the output sector are aligned,[16] allowing us to use the latter, $ln\ \widehat{Import_{ijs,t+y}^{In}}$, as a proxy for the former. Therefore, to explore the indirect effects on output

[16]Regarding output sectors, the direction of change in quantity is consistent with that of import value because we assume the import price remains constant over time.

sectors, we first regress the import value of input sectors on the policy dummy variable (EU ETS) in the first stage of the IV estimation. In the second stage, we regress the import and total values of the output sectors on the fitted import value of the input sectors.

4.3 Data

We construct a panel data of 76 countries over the period from 1995 to 2020. The dataset primarily comprises intercountry input-output (ICIO) tables from the OECD. We collect data on total and import values (trade flows) for all countries, excluding the five countries that joined the EU ETS from 2006 onward,[17] and retain only 2 input sectors and 12 output sectors out of 17 manufacturing sectors.[18] The input sectors are selected based on two criteria. First, the sector must fall under the regulation of CBAM to identify whether it is carbon-intensive. Second, to simplify the analysis, the sector must be within the regulatory scope of the EU ETS (Phase 1), which was implemented in 2005. Considering that the substitutability of goods varies depending on their features, we further classify the output sectors into two categories: those primarily producing intermediate goods and those producing final goods (hereafter referred to as the intermediate and final goods sectors, respectively). The intermediate goods sector is defined as a sector in which over half of the importing countries had a share of intermediate goods consumption exceeding 50% of the total consumption in 2004, the year before the introduction of the EU ETS. Similarly, the final goods sector is defined as a sector in which over half of the importing countries had a share of final goods consumption exceeding 50% of total consumption in 2004.[19] A summary of the sectoral classification is presented in Table A1 in Appendix A.

The ICIO table comprises 71 countries, of which 38 are OECD and 33 are non-OECD countries, after excluding the five mentioned earlier. Of the 38 OECD countries, 22 are importing countries in the treatment group. Accounting for this, there may be significant gaps in economic scale and trade volume between the countries in the treatment and control groups, which can influence the probability of treatment. To mitigate selection bias, we employ propensity score matching (PSM).[20] Following Austin (2011), we perform one-to-

[17] These countries are Bulgaria, Romania, Norway, Iceland, and Croatia. The exclusion is made to maintain the simplicity of the analysis. The EU ETS comprises three phases until 2020: Phase 1 (2005–2007), Phase 2 (2008–2012), and Phase 3 (2013–2020). Including all countries that introduced the EU ETS at some point would make the estimation models more suitable for the staggered DiD method. However, this would complicate the interpretation of results, especially since we also employ IV and PPML methods.

[18] Sector classification is based on two-digit divisions of ISIC Rev.4.

[19] We adopt a more flexible definition of intermediate and final goods sectors, following Saito (2004), to ensure that all sectors are classified into one of these two categories.

[20] PSM is conducted using the average data from the first year of the study period up to the year before the first treatment (1995–2004).

one nearest neighbor matching with a caliper of 0.2 standard deviations, as defined by the propensity score. We adopt the logarithm of GDP, manufacturing share, import share, and number of employers as covariates for PSM.[21] Data on these covariates are sourced from the World Bank DataBank. After applying the matching procedure, 13 importing countries remain in the treatment and control groups. The results of PSM are listed in Table 1. Since the absolute standardized mean difference (SMD) of each covariate is below 0.25,[22] we can conclude that the balance of most covariates has improved. The negative balance improvement for the logarithm of GDP indicates that the difference between the treatment and control groups increases after PSM. However, since the absolute SMD remains within the 0.25 threshold, the logarithm of GDP is still considered well-balanced. Fig. 2 illustrates the distribution of propensity scores before and after PSM, showing that importing countries in both groups have similar propensity scores, further confirming balance improvement.

Table 2 shows the descriptive statistics of the main outcome variables after the PSM procedure. Initially, the import and total values of the input sectors appear larger in the control group than in the treatment group. However, this difference is not a major concern because it becomes statistically insignificant when those values are transformed into a logarithmic form for the PPML estimation.

Data on carbon pricing and FTA are obtained from the World Bank and Japan External Trade Organization (JETRO), respectively.

[21] The covariates for PSM are selected to align the economic and trade scales between importing countries (Teixidó et al., 2019; Eskander and Fankhauser, 2023). Although it is common practice to use control variables as covariates in estimations, we exclude $jointFTA$ and $jointCP$ from the PSM procedure because the modes of these two variables take a value of zero for all importing countries in the data from 1995 to 2004.

[22] Various SMD cutoffs have been proposed, such as 0.1 and 0.25 (e.g., Austin, 2009; Normand et al., 2001; Stuart, 2010). We adopt the more lenient threshold of 0.25, because small sample sizes make it challenging to achieve a well-balanced outcome through PSM, even when the PSM model is properly specified (Austin, 2009).

Table 1: Balancing test results

	Status	Mean		SMD	Balance improvement (%)
		Treatment	Control		
ln GDP	U	25.57	25.64	-0.035	-533.4
	M	25.54	25.94	-0.224	
Manufacturing share	U	0.168	0.183	-0.381	56.56
	M	0.165	0.171	-0.165	
Import share	U	0.450	0.327	0.705	80.60
	M	0.404	0.380	0.137	
ln the number of employer	U	1.446	0.879	1.931	95.38
	M	1.460	1.433	0.089	

Notes: The table shows the results of nearest-neighbor PSM with a caliper of 0.2 standard deviations. Status "U" and "M" refer to unmatched and matched samples, respectively. The SMD indicates the standardized mean difference.

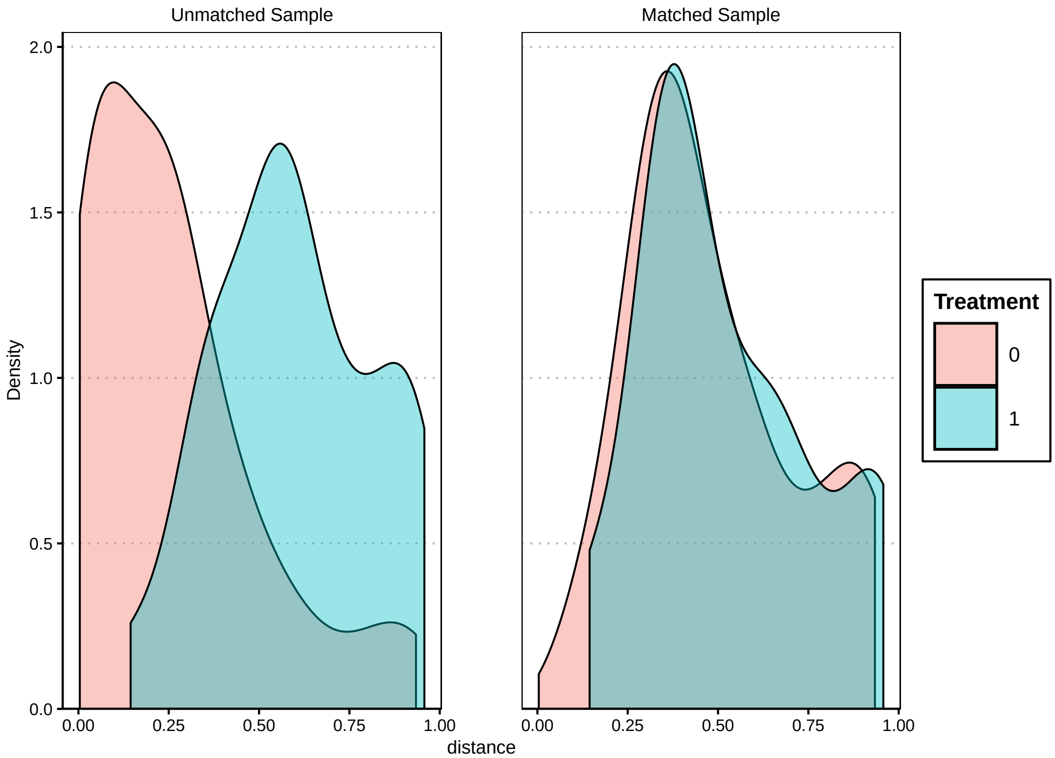


Fig. 2. Distribution of propensity scores by treatment and control groups

Notes: The figure shows the distribution balance for distance of the propensity score for control (pink) and treatment (blue) groups. The figure on the left and right sides show the distribution before and after the PSM procedure, respectively.

Table 2: Descriptive statistics

Statistic	Observations	Mean	SD	Min	Max
Treatment Group:					
Import value of input sectors	31,772	9,468	66,878	0.00	3,156,917
Total value of input sectors	31,772	2,765,102	6,450,767	5,627	57,358,342
Market share of input sectors	31,772	0.99	0.03	0.27	1.00
Import value of output sectors	381,264	22,822	198,742	0.00	15,951,723
Total value of output sectors	381,264	5,686,422	15,749,181	993	146,104,025
Market share of output sectors	381,264	0.99	0.04	0.01	1.00
Control Group:					
Import value of input sectors	47,320	47,571	343,334	0.00	15,907,057
Total value of input sectors	47,320	5,599,498	19,090,071	3,645	169,782,913
Market share of input sectors	47,320	0.99	0.05	0.21	1.00
Import value of output sectors	567,840	80,449	879,883	0.00	63,605,838
Total value of output sectors	567,840	11,042,336	40,701,243	0.00	612,369,116
Market share of output sectors	567,840	0.98	0.07	0.00	1.00

Notes: The unit of import and total values is thousand dollars. The observation numbers of treatment and control groups are different because the treatment group only includes trade countries pairs of EU importing countries and non-EU exporting countries, while the control group includes pairs of both EU countries and non-EU countries.

5 Results

5.1 Markets of Input Sectors

We begin by estimating the direct effects of the EU ETS on input sectors using equation 5. The results are presented in Table 3. Column (1) indicates a statistically significant increase in the import value of approximately 36% following the introduction of the EU ETS.[23] In Column (2), the coefficient of the EU ETS is not statistically significant, providing no evidence that the policy affects total value. Given that the import value constitutes less than 1% of the total value on average (see Table 2), the estimated increase in the import value is not substantial. The 36% upward shift in import value translates into an approximately 1.4% decline in market share. Nonetheless, our results support Hypothesis I-a and suggest that carbon pricing can slightly weaken the international competitiveness of

[23]The change is derived by $(e^{\beta_1} - 1) \times 100$, where β_1 is approximately 0.3055, as shown in Table 3.

countries implementing the policy within the domestic markets of input sectors. Based on the theoretical framework developed in Section 3, we can also infer a shift in demand within the input sectors from EU to non-EU countries. This shift leads to a decrease in the former's market share and a higher risk of carbon leakage, supporting Hypothesis I-b.

Table 3: The impacts on input sector markets

	(1)	(2)
Dependent Variables:	Import Value	Total Value
Variables		
EU ETS	0.3055*	-0.0048
	(0.1643)	(0.0082)
Joint FTA	0.0451	-0.0012
	(0.0742)	(0.0030)
Joint CP	-0.0002	0.0001
	(0.1582)	(0.0035)
Fixed-effects		
importer-year	Yes	Yes
exporter-year	Yes	Yes
year	Yes	Yes
pair-input sector	Yes	Yes
input sector-year	Yes	Yes
pair	Yes	Yes
Fit statistics		
Observations	79,092	79,092
Squared Correlation	0.96368	0.99964
Pseudo R^2	0.98034	0.99906

Notes: The coefficients reported in this table are derived from the regression using equation 5. Standard errors in parentheses are clustered at the pair-input sector level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

To provide graphical evidence of the above results, we perform a regression using equation 5 with 10 leads and 15 lags. Fig. 3 displays the evolution of the import and total values in input sector markets. First, we confirm the validity of the parallel trends assumption as almost no statistically significant pretrend exists, indicating no difference before the introduction of the EU ETS. Second, Fig. 3 shows that the import value increases after the EU ETS was introduced in 2005 (when the time of treatment is 0), while the total value has remained nearly unchanged since 1995. Third, the left side of Fig. 3 reveals that the input sectors experience a statistically significant increase in the import value for the first time in 2008, suggesting a delayed policy effect. Notably, this timing coincides with the onset of the EU ETS Phase 2, during which the futures prices of European Union Allowances (EUA) surged by $32 from nearly $0 (Huang et al., 2022).

Overall, our analysis of the impacts on the input sectors suggests that unilateral carbon pricing can influence market share and slightly weaken the international competitiveness of the importing country implementing the policy, thereby contributing to a higher risk of carbon leakage.

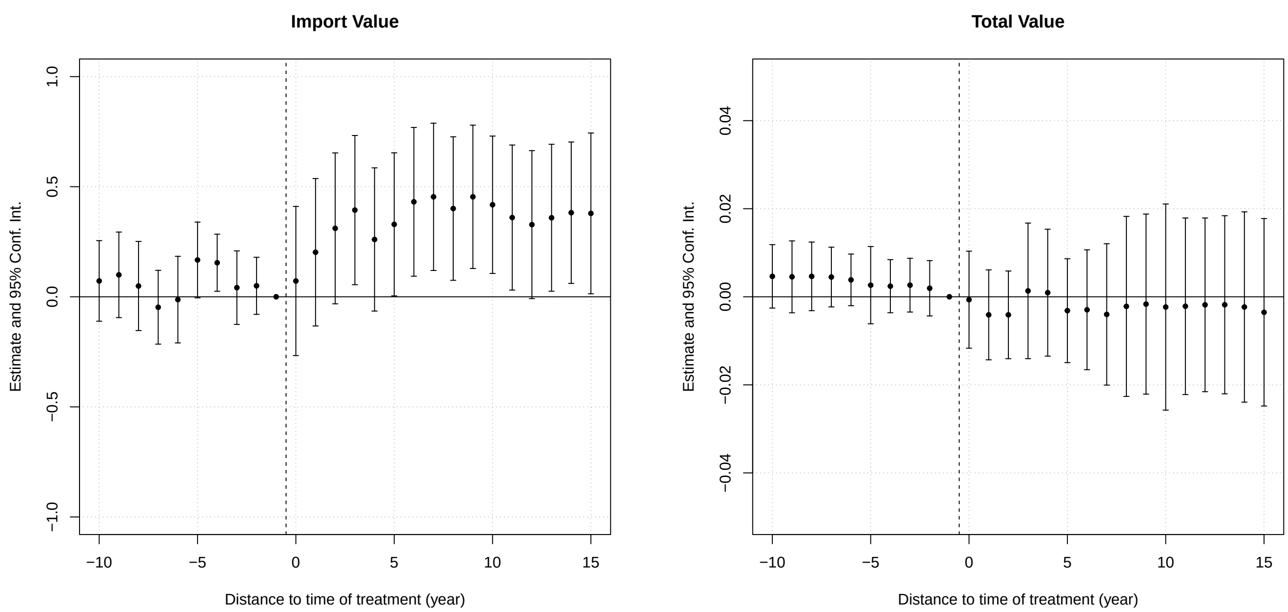


Fig. 3. Transition of the import and total values in markets of input sectors

Notes: The figure plots the transition of import and total values from 1995 to 2020 in input sectors using equation 5 with 10 leads and 15 lags. The distance to time of treatment = 0 indicates the year of commencement for EU ETS (2005).

Our findings on the loss of competitiveness in the input sectors differ from a significant body of early research that reports a limited or non-existent impact of the EU ETS on competitiveness (e.g., Anger and Oberndorfer, 2008; Chan et al., 2013; Marin et al., 2018; Petrick and Wagner, 2014). Most previous studies have conducted firm- or plant-level analyses, comparing entities subject to the ETS with those not covered by it within several EU countries, using competitiveness measures such as revenue, turnover, and value added. However, because these studies analyze competitiveness at the firm level, their insignificant results are not directly comparable with our findings, which focus on market share and international competitiveness.

Few studies have examined the global impact of the EU ETS. For instance, Naegele and Zaklan (2019) investigates its effects in the context of bilateral trade, finding evidence that the policy may increase import value by up to 0.052%, although this effect is not statistically significant.[24] Our findings partially align with those of this study, as we also observe a potential increase in import value. However, the estimates in column (1) of Table 3 indicate a substantially larger increase of 36%, suggesting carbon leakage.[25] Several factors may explain the discrepancies between our results and those of the previous study. First, the study periods differ: we use consecutive yearly data from 1995 to 2020, whereas Naegele and Zaklan (2019) analyze data from only three points in time (2004, 2007, and 2011). According to Piermartini and Yotov (2016), estimations using pooled data from consecutive years can yield results that differ from those based on interval data. In Section 5.4, we assess the impacts of the EU ETS on competitiveness using interval data, which suggests that a longer interval between observations leads to smaller estimated effects. Therefore, their conclusion of no carbon leakage does not necessarily contradict our framework. According to our theoretical framework, the magnitude of the effect of carbon pricing influences the level of carbon leakage risk. Another explanation for the differences in magnitude is the research design and objectives. Naegele and Zaklan (2019) examine country pairs where at least one of the trading partners has implemented the EU ETS, meaning they explore its effects on both imports and exports from ETS countries. Conversely, our study offers a distinct perspective by focusing on the effects of carbon pricing on imports, particularly by assessing its impacts on import dynamics.

5.2 Markets of Output Sectors

We analyze the indirect impacts of the EU ETS on two groups of output sectors, the intermediate and final goods sectors, by estimating equation 6. From Fig. 4, we do not observe any pretrends, indicating that in the absence of treatment, the import and total values for both the treated and control groups would have followed parallel paths over time. Additionally, we find no evidence that the EU ETS affects import or total values in the markets of either the intermediate or final goods sectors. The result suggests that the market shares of the output

[24]Following the specifications of Aichele and Felbermayr (2015), Naegele and Zaklan (2019) derive 0.052% considering the confidence interval of their results.

[25]Regarding bilateral trades, Naegele and Zaklan (2019) examine the impacts of the EU ETS on the embodied carbon imports and import values rather than total values. Moreover, we assume that the total values are unaffected by carbon pricing, while their study does not make this assumption when discussing carbon leakage. These differences make a direct comparison challenging.

sectors in countries with carbon pricing remain unchanged. In other words, countries participating in the EU ETS do not lose competitiveness in the output sector markets because of a lack of demand shifts, thereby preventing carbon leakage. Thus, we confirm Hypotheses II-a and II-b, while Hypotheses III-a and III-b are not supported by the estimation results.

Several potential explanations exist as to why we do not observe any effects on competitiveness and carbon leakage. One possibility is that goods from the input sectors account for only a small share of the total inputs required in the output sectors in EU countries. Another plausible explanation is government protection in the EU, where sectors shielded by regulations and subsidies experience less of an impact from carbon pricing. To explore this possibility, we examine the sectoral heterogeneity in the following subsection.

5.3 Sectoral Heterogeneity in Markets of Output Sectors

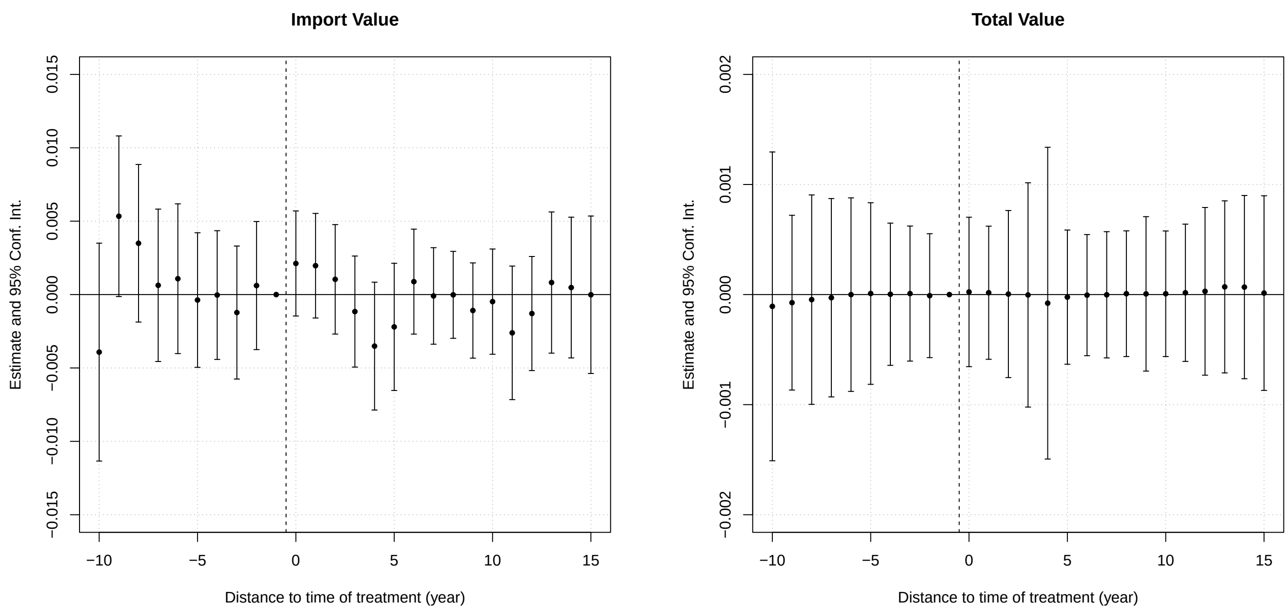
The level of protection across sectors may contribute to the heterogeneous impacts of carbon pricing. To examine this, we categorize the final goods sector into two groups: protected and non-protected.[26] In the EU, sectors such as textiles and vehicles face higher tariff rates. Therefore, we classify these sectors as protected sectors, while all other output sectors are considered non-protected (see Table A1 for more details).

Fig. 5(a) and (b) report the impacts on protected and non-protected sectors, respectively, based on the estimation of equation 6. We observe no statistically significant changes in these values for most of the study period. However, at certain points, a decline is noticeable in the import value in the protected sector markets, suggesting a slight increase in their market share. This is likely because government protection allows these sectors greater flexibility in setting prices to offset cost increases from the input sectors and prevent declines in quantity. In summary, regardless of the protection status, the competitiveness of the final goods markets appears unaffected by carbon pricing, providing no evidence of an increase in the risk of carbon leakage. Instead, the presence of protection may further mitigate the likelihood of carbon leakage.

These findings are relevant to the anti-leakage policies, including carbon tariffs, export rebates, output-based rebating, and CBAM, intended to enhance market competition. Typically, the effectiveness of such policies is assessed through ex ante numerical simulations using computable general equilibrium (CGE) models (e.g., Böhringer et al., 2017; Jia et al., 2024; Kuik and Hofkes, 2010), as their application remains in an exploratory phase. The econometric approach employed in this study, grounded in the theoretical framework outlined in Section 3, complements the results from the CGE model by providing empirical insights into how these policies may function in practice.

[26] We analyze only the final goods sectors in this section, as none of the intermediate goods sectors are classified as protected sectors.

(a) Markets of intermediate goods sectors



(b) Markets of final goods sectors

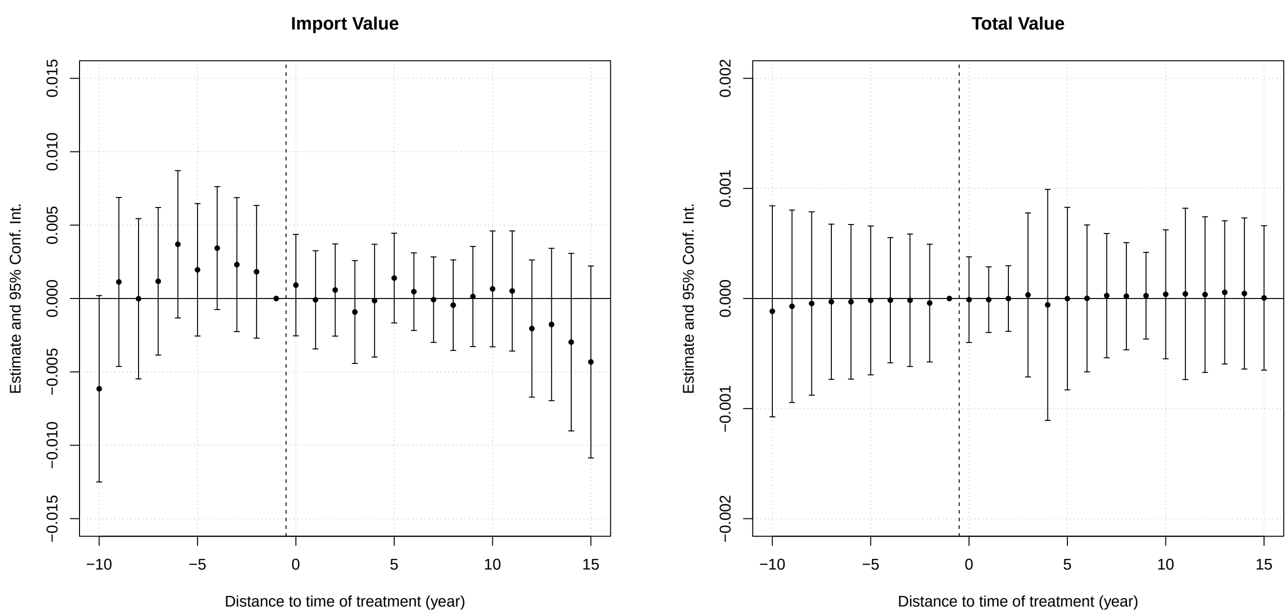
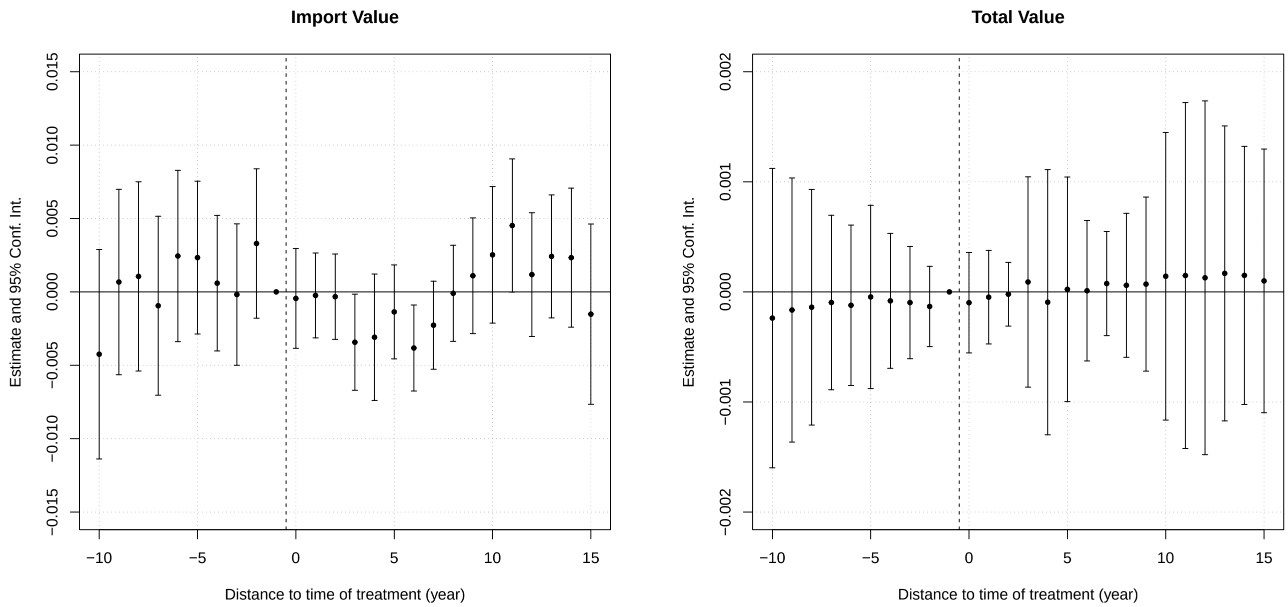


Fig. 4. Transition of the import and total values in output sector markets

Notes: The figure plots the transition of import and total values from 1995 to 2020 in the intermediate goods sectors and final goods sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of protected sectors



(b) Markets of non-protected sectors

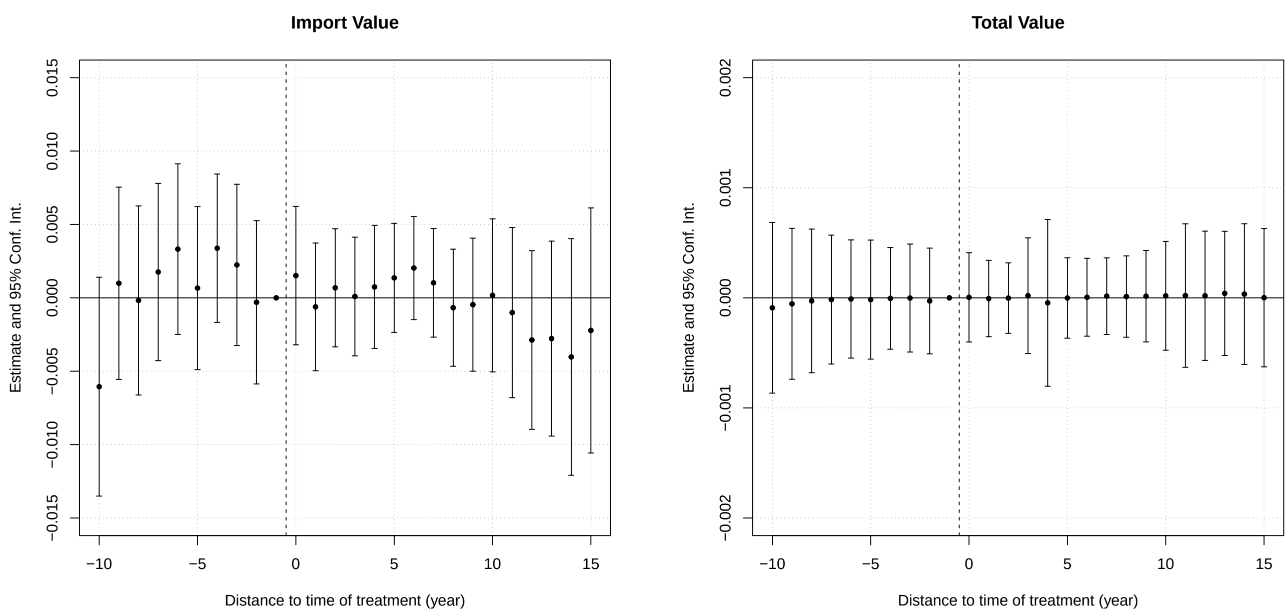


Fig. 5. Transition of the import and total values in markets of final goods sectors: heterogeneity in the level of protection

Notes: The figure plots the transition of import and total values from 1995 to 2020 in protected sectors and non-protected sectors, shown in (a) and (b), respectively, which are derived using equation 6. The distance to time of treatment= 0 indicates the year of commencement for the EU ETS (2005).

5.4 Robustness Checks

To confirm the robustness of our main results, we conduct several additional analyses. These results are provided in Appendix B. First, we estimate the effects of the EU ETS using panel data with time intervals. Piermartini and Yotov (2016) emphasizes the importance of confirming estimated results with data pooled over consecutive years. This is particularly important because in FE estimation, the dependent and independent variables cannot perfectly adjust for yearly effects. The impacts of the policy may sometimes lag behind its implementation, leading to imprecise estimations. To address this, we employ 3- and 5-year intervals to analyze both the direct and indirect effects.

The results of 3-year intervals, presented in Columns (1) and (2) of Table B1, are nearly identical to the main results, although the impacts on the input sectors are slightly larger than those in the baseline analyses. We also confirm the robustness of the results shown in Fig. B1 to Fig. B3. The EU ETS appears to reduce the competitiveness of the input sectors in importing countries, increasing the risk of carbon leakage, while not affecting the market for output sectors. The primary difference from the baseline results is that the 3-year interval results suggest the potential convergence of the direct effects, indicating that carbon pricing impacts competitiveness and carbon leakage only in the short run. Furthermore, carbon pricing does not weaken the competitiveness of either protected or non-protected sectors, which is consistent with the baseline results.

In contrast, the results of 5-year intervals show no impact of carbon pricing on either the input or output sectors, as illustrated in Fig. B4 to Fig. B6. Column (3) of Table B1 indicates that the coefficient of import value is positive but statistically insignificant. These findings suggest that the long-term effects of carbon pricing on trade flows may be too small to significantly influence either the input or output sectors.

As a further robustness check, we apply a different matching method using the same caliper as in the baseline analysis. Following Cochran and Rubin (1973) and Rosenbaum and Rubin (1985), we use the Mahalanobis distance for matching instead of the propensity score. After the matching procedure, 13 importing countries remain in the treatment and control groups. The results, presented in B1 and Fig. B7 to Fig. B9, are nearly identical to those of the main analyses.

6 Conclusion

This study examines the effects of unilateral carbon pricing on international competitiveness and carbon leakage in both the targeted (input) and non-targeted (output) sectors. While earlier research largely focuses on the direct effects on targeted sectors, our study extends the analysis to non-targeted sectors, thereby providing a better understanding of the impacts of carbon pricing.

This study's key findings can be summarized as follows. First, unilateral carbon pricing applied solely to the importing country weakens its competitiveness in the input sectors, leading to potential carbon leakage. Second, the policy does not affect the competitiveness of the output sectors regardless of whether their goods are primarily used as intermediate or final products, suggesting that carbon leakage is unlikely to occur in these sectors. Third, compared with non-targeted sectors without government protection, protected sectors in the importing country appear to be more effective in mitigating the risk of carbon leakage.

These findings have important implications for climate policy design within the global supply network. First, policymakers should carefully assess the potential competitiveness losses and carbon leakage risks when applying carbon pricing to goods from highly import-dependent sectors. Second, concerns over the indirect negative effects on non-targeted sectors may be overstated, allowing policymakers to focus on mitigating competitiveness losses and carbon leakage risks in targeted sectors. Finally, carbon pricing should ideally be complemented by other policy instruments. Although the overall impact on competitiveness is modest, the risk of shifting GHG emissions to other regions remains. Our findings suggest that industry protection measures can mitigate this risk; however, such measures may conflict with the broader goal of promoting free trade. To balance economic and environmental priorities, expanding CBAM globally could be a viable approach for mitigating global carbon emissions and maintaining trade openness.

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Appendix

A Sectoral classification

Table A1: Sectoral classification

Sector		ISIC Rev.4	Description
Input Sector			
		C23	Manufacture of other non-metallic mineral products
		C24	Manufacture of basic metals
Output Sector			
Intermediate Goods Sector		C16	Manufacture of wood and products of wood and cork, except furniture; manufacture of articles of straw and planting metals
		C22	Manufacture of rubber and plastics products
		C25	Manufacture of fabricated metal
		C27	Manufacture of electrical equipment
Final Goods Sector	Protected sector	C13, C14, C15	Manufacture of textiles, manufacture of wearing apparel, and manufacture of leather and related products
		C29	Manufacture of motor vehicles, trailers and semi-trailers
	Non-protected sector	C10, C11, C12	Manufacture of food products, manufacture of beverages and, manufacture of tobacco products
		C21	pharmaceuticals, medicinal chemical and botanical products
		C26	Manufacture of computer, electronic and optical products
		C28	Manufacture of machinery and equipment n.e.c.
		C30	Manufacture of other transport equipment
		C31, C32, C33	Manufacture of furniture, other manufacturing, and repair and installation of machinery and equipment

Notes: The table displays the sectoral classification in this paper based on the classification of ISIC Rev.4. We first define input and output sectors, and then separate output sectors into two groups: Intermediate goods and final goods sectors. Finally, final goods sectors are divided into protected and non-protected sectors.

B The Results of Robustness Checks

Table B1: The impacts on input sector markets: robustness checks

	3-Year Intervals		5-Year Intervals		Mahalanobis	
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variables:	Import Value	Total Value	Import Value	Total Value	Import Value	Total Value
Variables						
EU ETS	0.3413**	-0.0049	0.2749	-0.0051	0.3909**	-0.0033
	(0.1722)	(0.0091)	(0.1870)	(0.0103)	(0.1621)	(0.0082)
Joint FTA	0.0732	-0.0014	0.1427	-0.0009	0.0690	-0.0012
	(0.0765)	(0.0030)	(0.1016)	(0.0036)	(0.0720)	(0.0034)
Joint CP	0.0139	0.0000	0.0757	0.0008	-0.0167	0.0000
	(0.1567)	(0.0035)	(0.1849)	(0.0043)	(0.1562)	(0.0040)
Fixed-effects						
importer-year	Yes	Yes	Yes	Yes	Yes	Yes
exporter-year	Yes	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes	Yes
pair-input sector	Yes	Yes	Yes	Yes	Yes	Yes
input sector-year	Yes	Yes	Yes	Yes	Yes	Yes
pair	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	27,378	27,378	18,252	18,252	79,092	79,092
Squared Correlation	0.96735	0.99970	0.95823	0.99959	0.96320	0.99954
Pseudo R^2	0.98019	0.99912	0.97832	0.99901	0.97935	0.99888

Notes: The coefficients reported in this table are derived from the regression using equation 5. Columns (1) and (2) show the results of study period with 3-year intervals, and Columns (3) and (4) show those with 5-year intervals. Columns (5) and (6) present the results of estimations using the Mahalanobis matching with a caliper of 0.2 standard deviations. Standard errors in parentheses are clustered at the pair-input sector level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

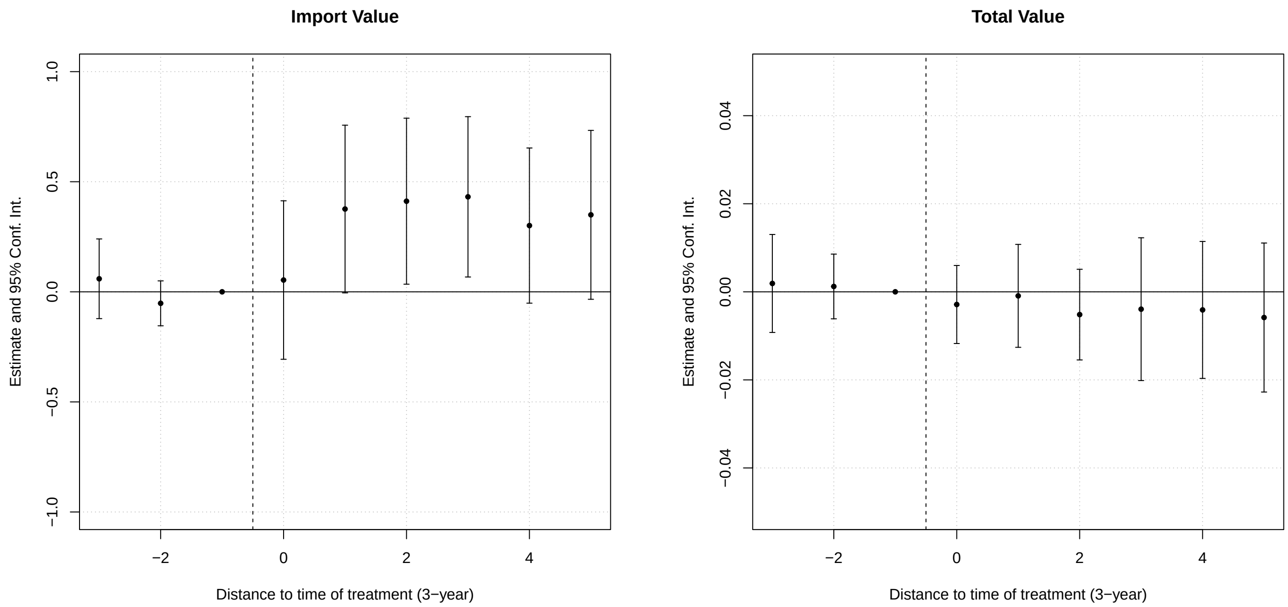
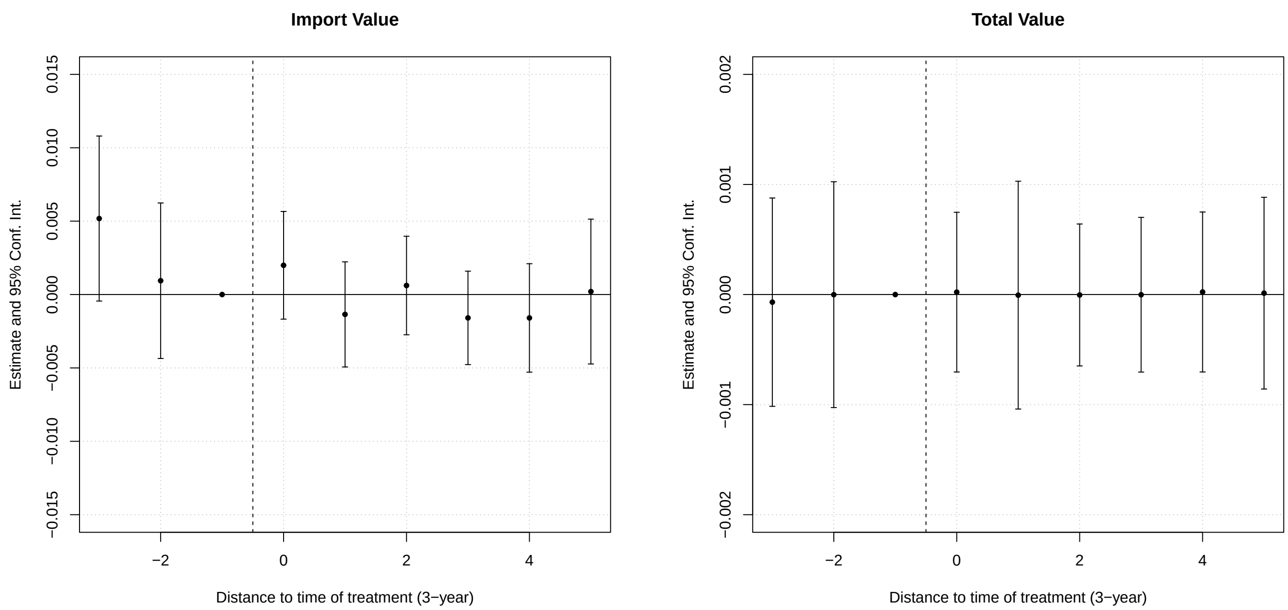


Fig. B1. Transition of the import and total values in markets of input sectors: 3-year intervals

Notes: The figure plots the transition of import and total values from 1996 to 2020 with 3-year intervals in input sectors using equation 5 with 10 leads and 15 lags. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of intermediate goods sectors



(b) Markets of final goods sectors

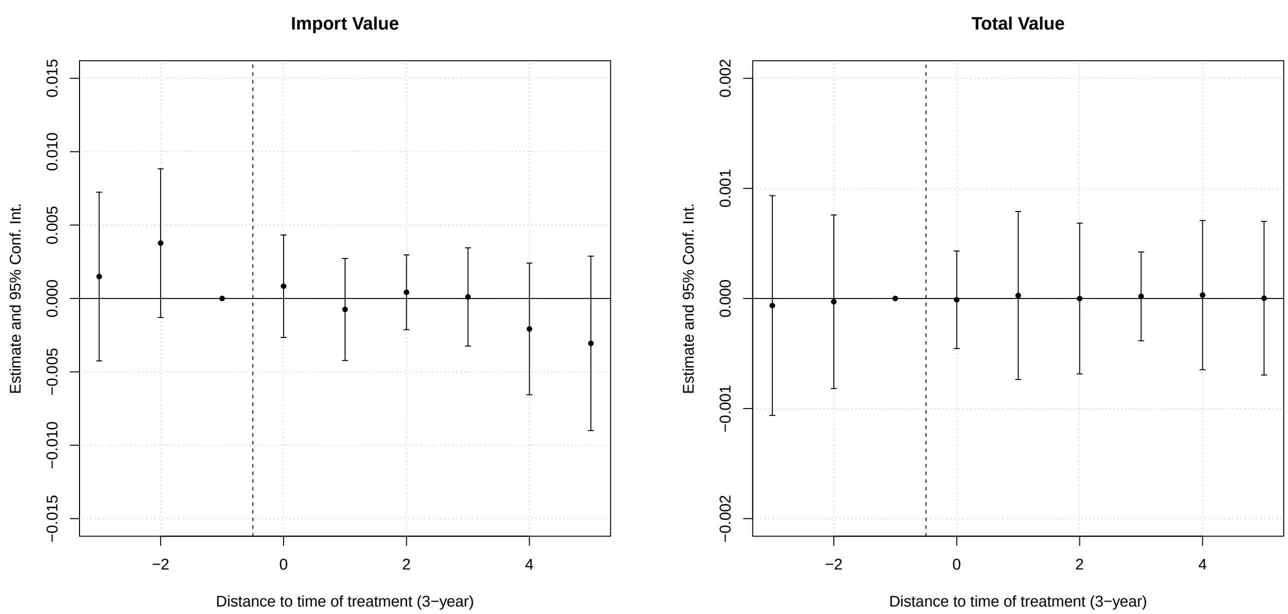
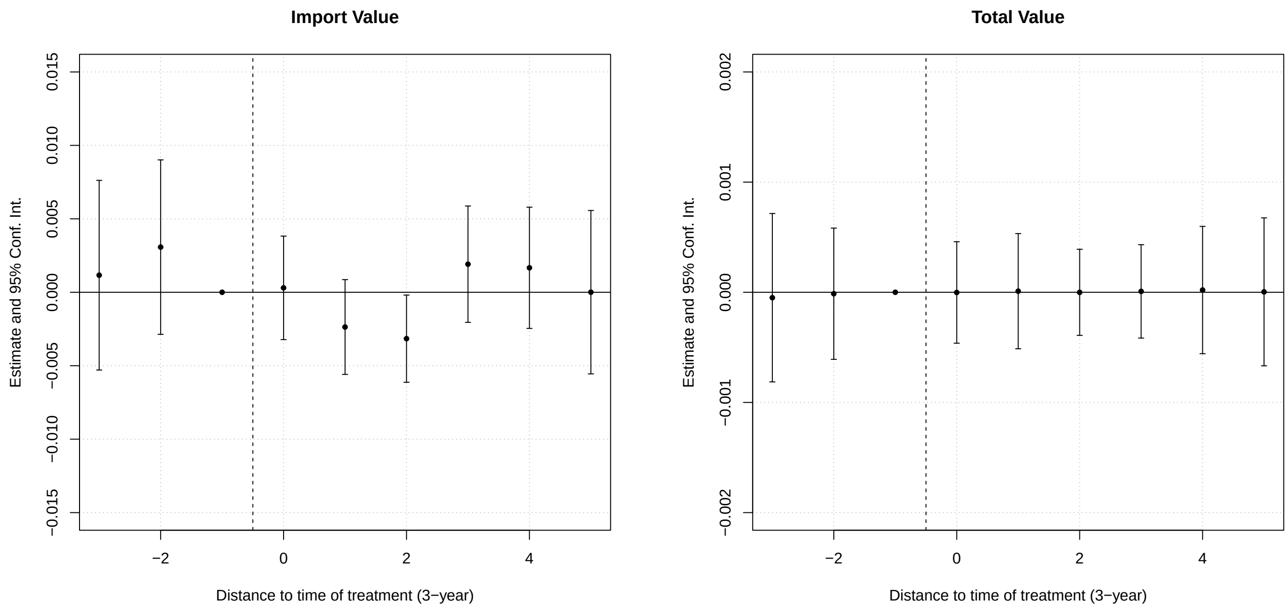


Fig. B2. Transition of the import and total values in markets of output sectors: 3-year intervals

Notes: The figure plots the transition of import and total values from 1996 to 2020 with 3-year intervals in the intermediate goods sectors and final goods sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of protected sectors



(b) Markets of non-protected sectors

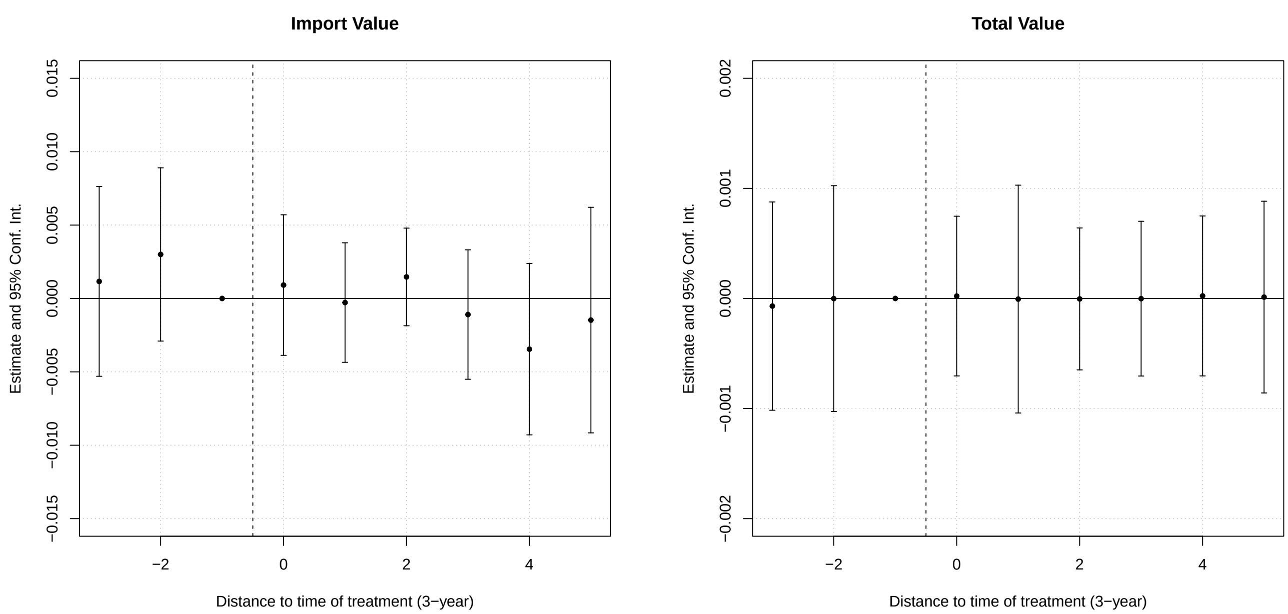


Fig. B3. Transition of the import and total values in markets of final goods sectors: heterogeneity in the level of protection, 3-year intervals

Notes: The figure plots the transition of import and total values from 1996 to 2020 with 3-year intervals in protected sectors and non-protected sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

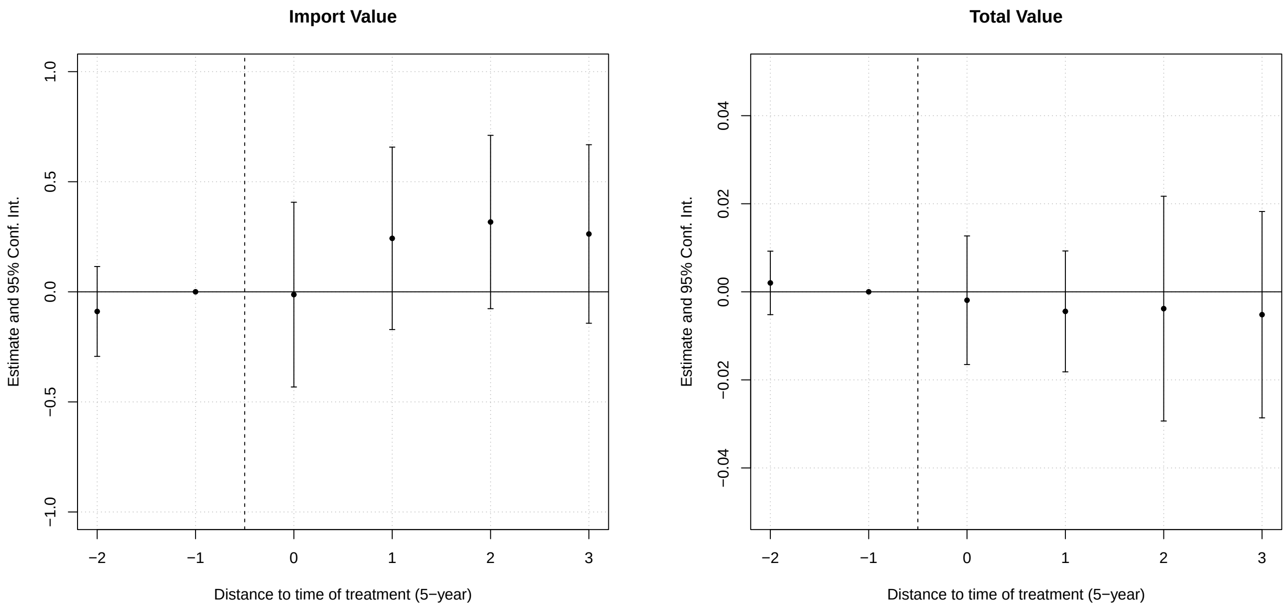
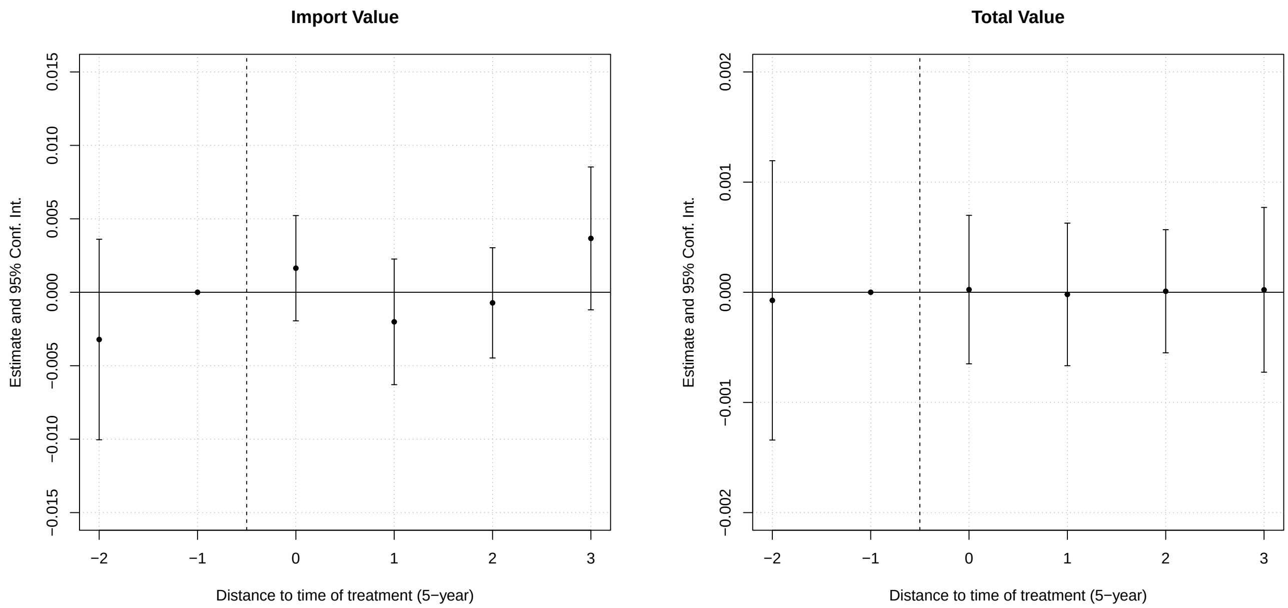


Fig. B4. Transition of the import and total values in markets of input sectors: 5-year intervals

Notes: The figure plots the transition of import and total values from 1995 to 2020 with 5-year intervals in input sectors using equation 5 with 10 leads and 15 lags. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of intermediate goods sectors



(b) Markets of final goods sectors

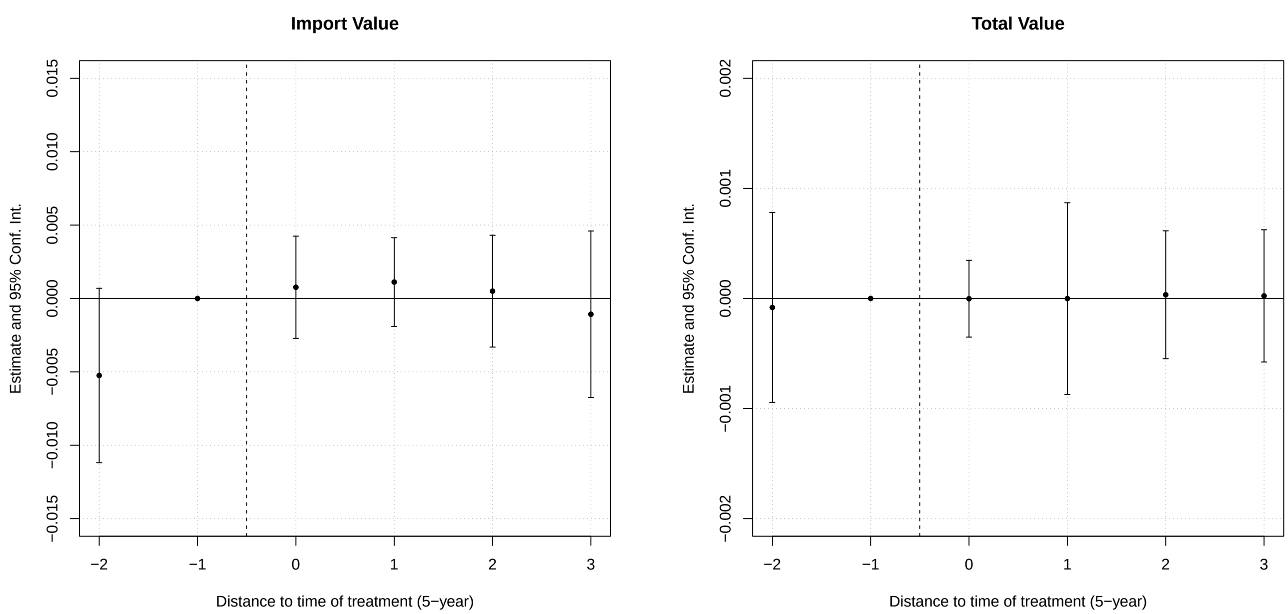
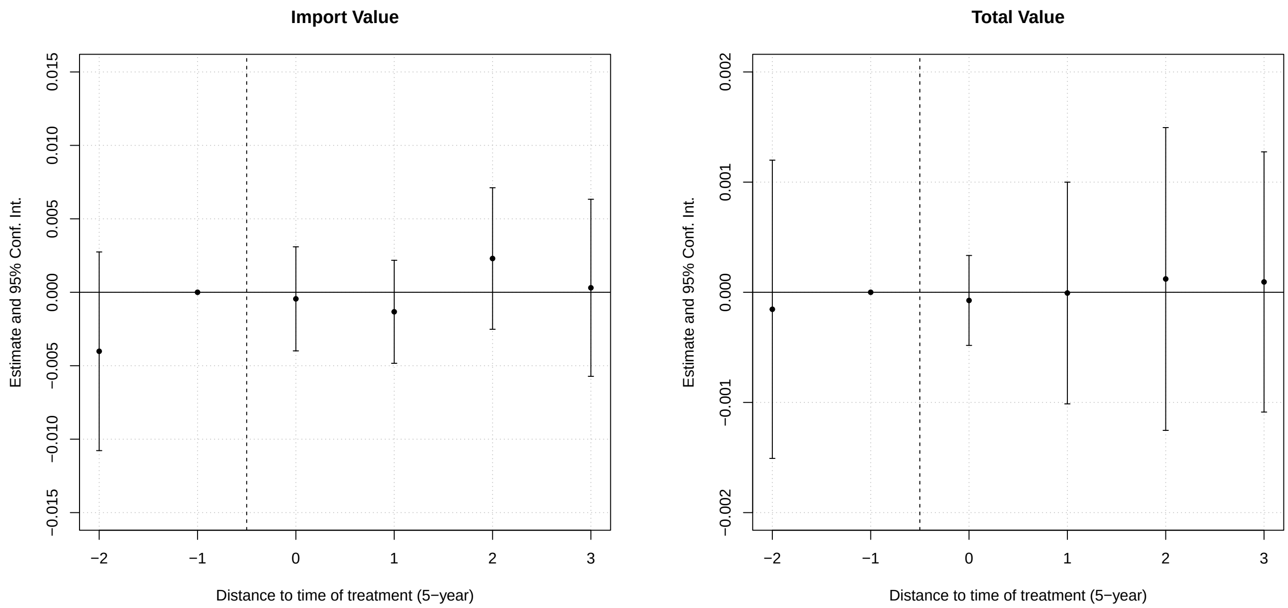


Fig. B5. Transition of the import and total values in markets of output sectors: 5-year intervals

Notes: The figure plots the transition of import and total values from 1995 to 2020 with 5-year intervals in intermediate goods sectors and final goods sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of protected sectors



(b) Markets of non-protected sectors

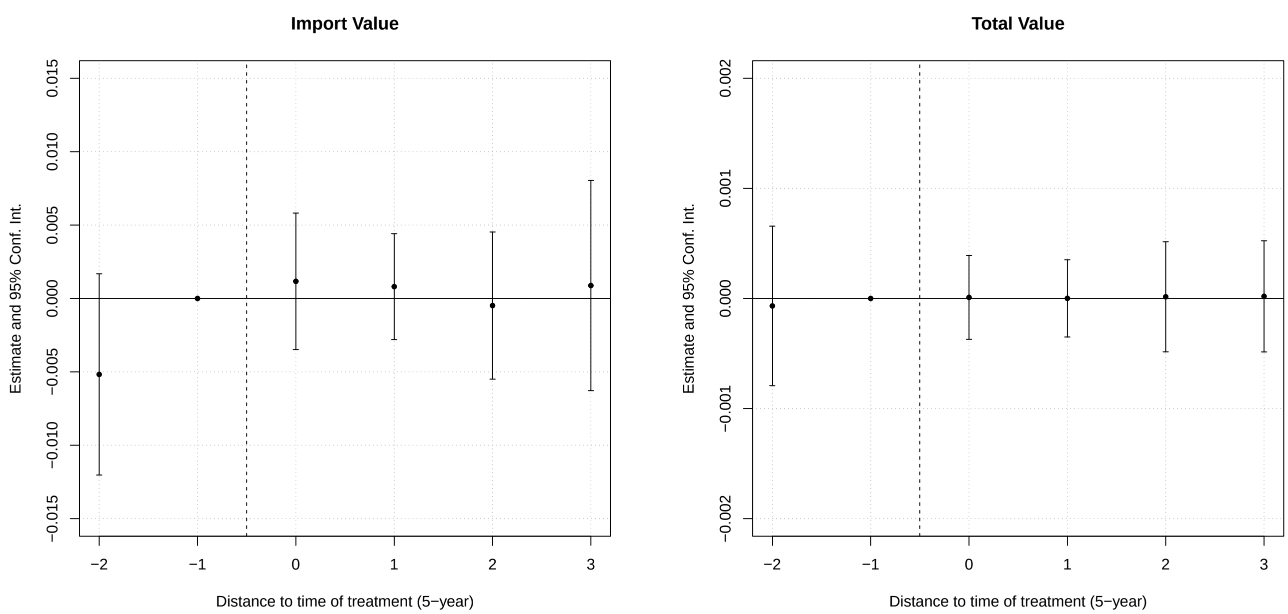


Fig. B6. Event study of the import and total values in markets of final goods sectors: heterogeneity in the level of protection, 5-year intervals

Notes: The figure plots the transition of import and total values from 1995 to 2020 with 5-year intervals in protected sectors and non-protected sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

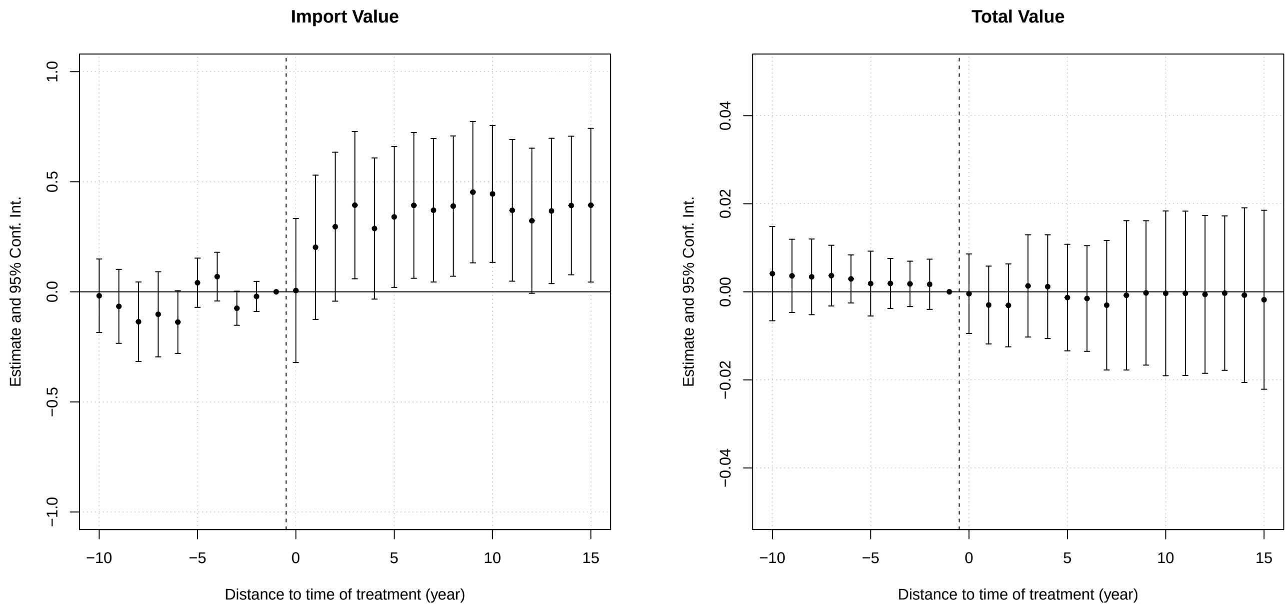
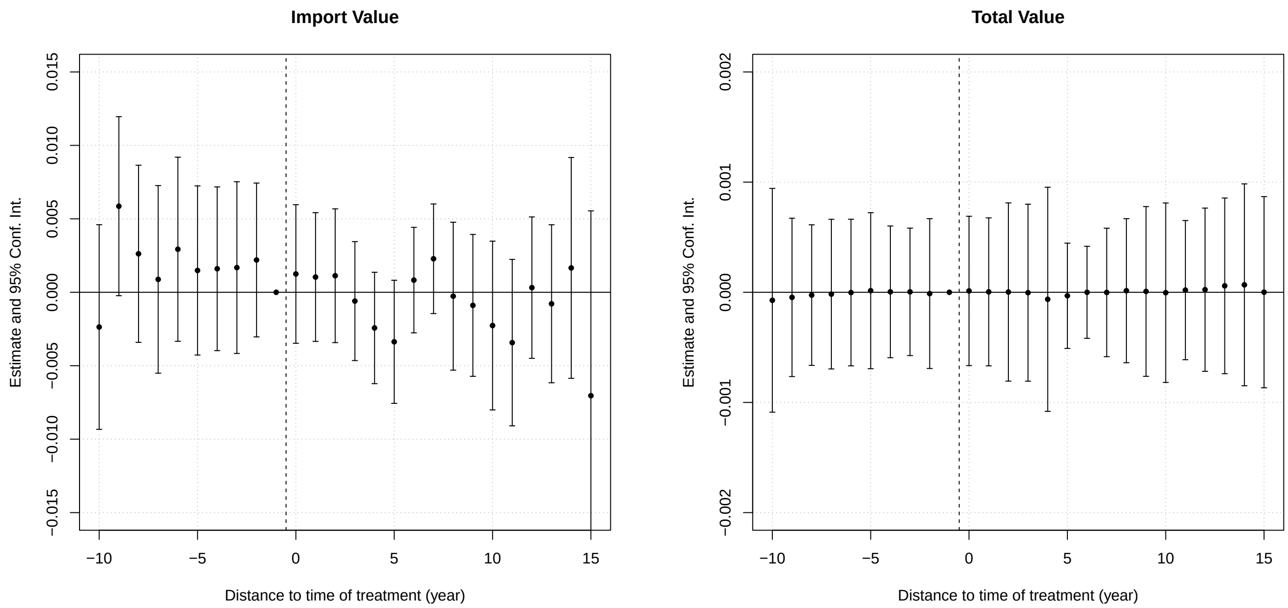


Fig. B7. Transition of the import and total values in input sector markets: Mahalanobis matching with a caliper

Notes: The figure plots the transition of import and total values from 1995 to 2020 using equation 5 with 10 leads and 15 lags. The data are processed using the Mahalanobis matching with a caliper of 0.2 standard deviations. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of intermediate goods sectors



(b) Markets of final goods sectors

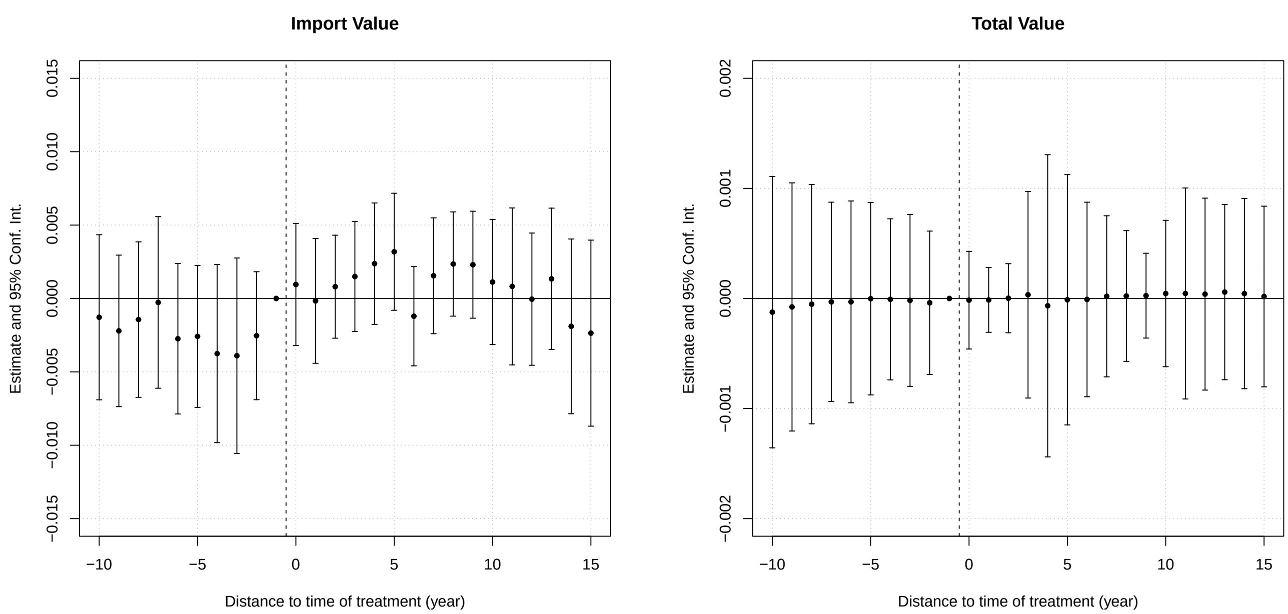
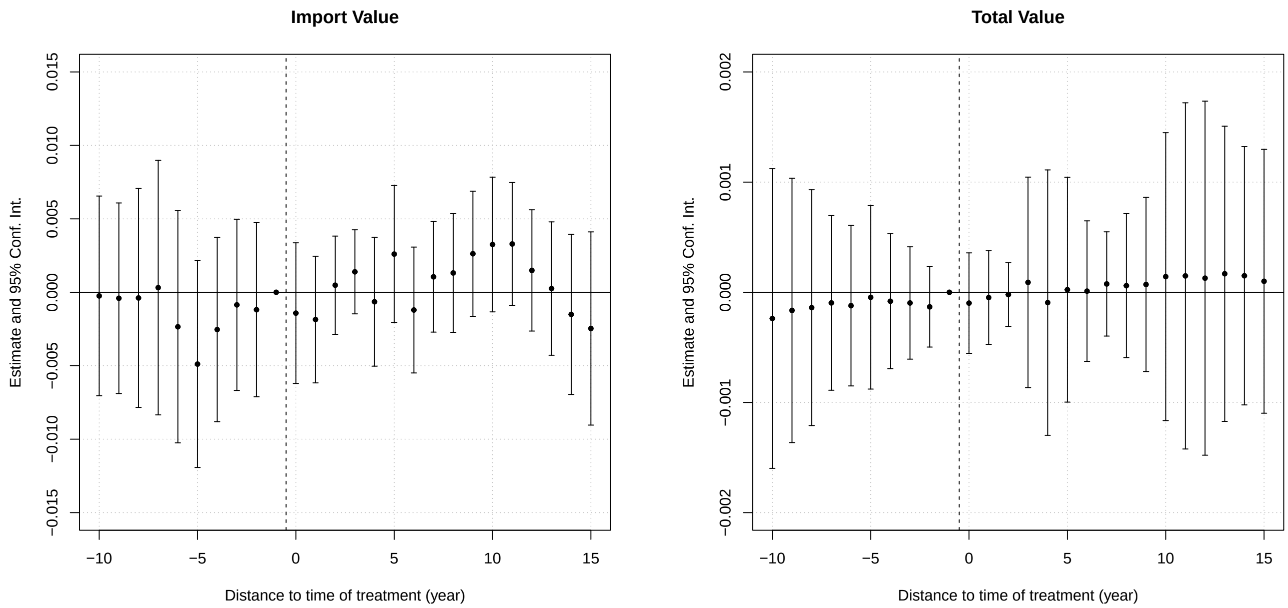


Fig. B8. Transition of the import and total values in output sector markets: Mahalanobis matching with a caliper

Notes: The figure plots the transition of import and total values from 1995 to 2020 in intermediate goods sectors and final goods sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The data are processed using the Mahalanobis matching with a caliper of 0.2 standard deviations. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).

(a) Markets of protected sectors



(b) Markets of non-protected sectors

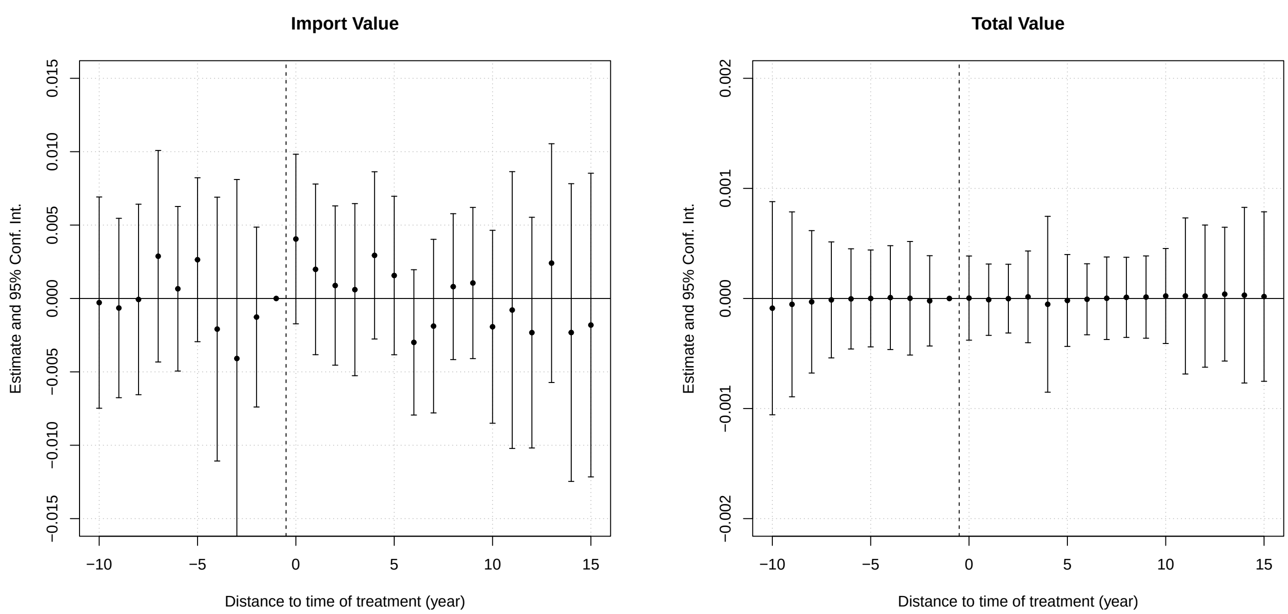


Fig. B9. Transition of the import and total values in markets of final goods sectors: Mahalanobis matching with a caliper

Notes: The figure plots the transition of import and total values from 1995 to 2020 in protected sectors and non-protected sectors, shown in (a) and (b), respectively, which are derived by using equation 6. The data are processed using the Mahalanobis matching with a caliper of 0.2 standard deviations. The distance to time of treatment = 0 indicates the year of commencement for the EU ETS (2005).