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PAPER

Emissions trading system: bridging the gap between environmental targets and fair competition

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Abstract

The effectiveness of the European Emissions Trading System in supporting a level playing field while reducing total emissions is tested. While data show a robust impact on the environment as a steady decrease in carbon emissions is observed, it is reported that its ability to internalize emission costs may improve to better address the import of extra European generated emissions that negatively impact the economy when not properly accounted for. Analyzing data in six European countries between 2016 and 2020, the results suggest competitive advantages for industries with higher extra-European imports of inputs that result in biased production costs that, in turn, alter competitive positioning. The novelty lies in focusing on the threats to fair competition within Europe along with the well-known carbon leakage risk widely investigated by previous literature. Complementary policy tools capable of internalizing emission costs, regardless of their origin, are necessary to improve the healthy functioning of the system. In this regard, carbon taxation may outperform carbon border adjustment, as it is based on consumption patterns. Our results can aid policymakers in designing impact analyses aimed at limiting potential distortions to Europe's level playing field.

1. Introduction

There is a broad consensus on the importance of carbon pricing programs, especially cap-and-trade mechanisms, for economically efficient climate policies [1–3]. A well-known European carbon pricing instrument is the emission trading system (ETS), a pillar of European environmental policy [4]. It is a cap-and-trade approach in which the cap decreases over time [5] and installation owners can trade allowances following market-based opportunity decisions [6]. With the Green Deal, the European Commission intends to achieve climate neutrality by 2050 [7] boosted by the Fit-for-55 package [8]: a set of proposals to pave the way for decarbonization goals [9]. The package includes major initiatives on effort-sharing regulation [10], land use, forestry, alternative fuel infrastructure, measures aimed at reducing carbon leakage, and ETS.

Previous literature has raised issues related to the effectiveness of ETS in internalizing the environmental costs associated with extra-EU imports. The scope of passing through carbon costs into the final product prices is a key issue that can pave the way to carbon leakage [11, 12].

Thus far, some scholars have argued that the ETS has struggled to preserve fair competition from extra-EU-located companies that are not subject to similar schemes. In addition, issues have been raised regarding the ETS scope and how and to what extent the polluter-pays principle is respected [13, 14], although the system foresees free allowances to installations that are thought to be at substantial risk of carbon leakage [11, 15]. To address the aforementioned biases, several measures have been proposed [16]; however, they fail to consider the potential distorting effects between EU countries due to different penetrations of extra-EU imports.

We analyze the effectiveness of the ETS in promoting an equitable distribution of pollution prevention costs, that is, a *condition sine qua non* for evaluating carbon pricing programs [17, 18], along with its efficiency in keeping a level playing field so that environmental and economic sustainability go hand in hand.

Two research questions were defined: RQ1: How well does the ETS comply with the polluter pays principle? The hypothesis is that because of the ETS functioning mechanism, it is hardly respected. RQ2: Is the ETS capable of guaranteeing a level playing field between the productive sectors of the member states? The hypothesis is that the ETS has failed to internalize the negative externalities associated with the import of goods and services.

To answer RQ1, we identified the key determinants of emission accounts deemed to determine free allowances. Thereafter, we compared the estimated allocation with the actual allocation. To answer RQ2, the differences between the predicted and actual free allowances were ranked to measure the imbalances among countries and sectors. Subsequently, we predicted the gap between the actual emissions and those covered by the ETS and compared the fitted and observed values to compute a vector of residuals used to rank sectors according to the residuals.

We found that the ETS's efficiency in allocating costs to polluters varies, and discrepancies exist in its ability to internalize costs across different sectors; the ETS's differing effects across sectors suggest potential distortions in the single market.

The results have policy implications, providing evidence of the need to supplement the ETS with complementary policy measures to ensure that polluters bear the costs of implementing measures to prevent and control pollution to preserve the environment. It is necessary to intervene in the ETS by swiftly integrating mechanisms capable of efficiently internalizing the cost of emissions generated by extra-EU imports of intermediate input to reduce unfair competition.

The remainder of this paper is organized as follows: section 2 provides a review of the background literature, section 3 outlines the analytical approach, section 4 presents key results that are discussed in section 5, and conclusions follow.

2. Background

Carbon pricing plays a prominent role in political efforts to limit the global average temperature increase to 1.5 °C–2 °C above preindustrial levels [18] given that it aims to internalize the external costs of emissions and link them to their sources through a price signal. The world's first international carbon market, the ETS, was launched in 2005 [19]. It has evolved since it was introduced, changing how allowances are allocated and introducing new rules. These changes have aimed to improve the effectiveness and efficiency of the ETS [20]. As a result of these changes, the incentives for innovation and adoption of low-carbon technologies are probably stronger today than ever before [21].

Since its start, the ETS has evolved through several distinct phases. The initial phase (2005–2007) was a trial period in which the EU learned valuable lessons about the allocation of allowances and the design of the system [22]. The second phase (2008–2012) saw the introduction of more stringent emissions caps and the expansion of the ETS to include additional sectors and gases [23]. The third phase (2013–2020) marked a significant shift in the allocation of allowances, with a transition to auctioning and the establishment of the Market Stability Reserve to address the surplus of allowances [24]. Since its inception, the ETS has brought results that have contributed to its success in the reduction of greenhouse gas emissions [25, 26].

By placing a price on carbon and allowing companies to trade allowances, the system incentivizes firms to seek the most efficient methods for reducing emissions [27]. This market-based approach has proven to be more cost-effective than traditional command-and-control regulatory measures [28], and from an economic standpoint, it has been efficient in reaching environmental targets while maximizing social welfare by letting the market play a prominent role in it.

The ETS has also played an important role in stimulating innovation and technological progress in low-carbon technologies [29]. By creating a financial incentive for companies to reduce emissions, the system has encouraged investment in research and development and the introduction of new technologies [29]. The ETS is an instrument that allows companies to choose the most appropriate emissions reduction strategy for which flexibility has contributed to the overall effectiveness and cost-efficiency of the system [30].

The ETS has also contributed to international cooperation on climate change mitigation by serving as a model for other emissions trading schemes around the world [31]. Global policy asymmetries in climate policy necessitate adjustments to the European carbon market as well as new mechanisms that consider extra-EU emissions. The absence of a global carbon market can result in carbon leakage, especially if carbon prices are destined to increase to achieve new climate targets [32]; from this perspective, it is worth noting that the carbon price has often been used as an indicator of the effectiveness of the ETS [33]. Some scholars have underlined that the new 2050 targets can be achieved if the ETS parameters are properly updated [8].

However, the ETS has faced several challenges and weaknesses that have been examined in the literature, despite its various strengths.

A prominent shortcoming of the ETS was the allocation of allowances, which resulted in oversupply and volatile prices [34]. This oversupply has weakened the incentive for firms to reduce emissions, undermining the effectiveness of the system in achieving its overall emissions reduction targets [23].

Its limited scope, covering only certain sectors and greenhouse gases, is another weakness. This has led to concerns about the system's ability to comprehensively address emissions and achieve more ambitious climate goals [35]. Consequently, the effectiveness of the ETS in reducing emissions could potentially be increased by extending it to additional sectors and gases.

Another widely discussed concern is carbon leakage, where firms move production to countries with more lenient climate policies, increasing global emissions [36], as from the inception of the ETS, the issues of competition and competitiveness have been highlighted [37]. Indeed, while a relative cap-and-trade system could help to prevent any detrimental impact on competitiveness, it might not result in the most cost-effective emission reductions. Although the literature also showed that during the first two phases of the ETS, negative effects on the competitiveness of firms were limited [34], we argue that the connections between international competition and the constraints imposed on firms covered by the ETS system have recently increased considerably. This raises questions about the ETS's effectiveness in addressing global emissions and its potential negative impact on European industry's competitiveness [11]. Considering that one of the key success factors in Europe's implementation of the ETS is the single economic market, which extends to form a common environmental market [22], we argue that this successful factor is currently under pressure due to its design for internalizing the costs of emissions and challenges in integrating it with additional climate policies. While the subject of carbon leakage has been extensively discussed, we contribute to the literature by shedding light on internal issues that have often been overlooked thus far.

The lack of harmonization with other climate policies at the national and regional levels, which can lead to overlapping regulations and inefficiencies, is also a challenge for the ETS [38]. The overall effectiveness of the ETS and a more comprehensive approach to tackling emissions can be improved by coordinating it with other climate policies [39].

To conclude, regarding the relation between the functioning of the ETS and fair competition, some concerns have been raised. Carbon leakage given that industries exposed to international competition might relocate their production to countries with less stringent climate policies [4, 32, 36]. The competitiveness of energy-intensive industries has also been a prominent topic in previous literature: compliance costs might disproportionately affect energy-intensive industries [40] as in the early stages power producers and energy-intensive industries were treated similarly, structural differences between these industries [41]; no wonder that previous literature has also analyzed the vulnerability of an energy intensive sector to the ETS [42].

Similarly, scholars have argued that the free allocation of allowances and the method of their distribution could create competitive advantages for some industries or countries [43]; in this context, the long-running dilemma over the allocation of CO2 allowances is a window into the political economy of the ETS [44]. Consequently, arguments have been made regarding the efficiency of the ETS in providing sufficient incentives for industries to invest in low-carbon technologies, hampering long-term competitiveness [45, 46].

We add up to this field of studies assessing the ETS in light of the polluter pays principle and competition, highlighting potential concerns related to the allocation of allowances and the role of imported emissions.

We note that the degree of compliance with the polluter pays principle, i.e., adequate accountability for emissions generated, varies across industrial sectors, raising concerns about its impact on the healthy functioning of competition in the EU. These differences in emissions accountability depend primarily on extra-EU imports of inputs by European industry and on final consumption.

The added value of this paper lies in its peculiar analysis of the ETS, which combines an assessment of its compliance with the polluter-pays principle with an assessment of its ability to ensure a level playing field for all industries, thus providing new insights into the effectiveness of the system and the policy implications that have not been explored in previous literature.

3. Research design and methods

The ETS operates in the EU and in Iceland, Liechtenstein, and Norway, covering roughly 10,000 installations, which generate approximately 41%–43% of European emissions. The sample contains data from Germany, France, Italy, Poland, Spain, and the Netherlands, as shown in figure 1, for the 2016–2020 period. Specifically, the following manufacturing sector; see NACE Rev. 2 nomenclature for a detailed description of codes: C10-C12: Food, beverages and tobacco, C13-C15: Textiles, leather, and related, C16: Wood and cork, C17: paper products, C18: Printing, C19: Coke and petroleum products, C20: Chemicals, C21: Pharmaceutical products, C22: Rubber and plastic, C23: Nonmetallic mineral products, C24: Basic metals, C25: Metal products, C26:

Figure 1. Research scope and framework. Source: Own elaboration, the GDP of the sample equals 72.4% of 14.2 trillion € EU-27 GDP.

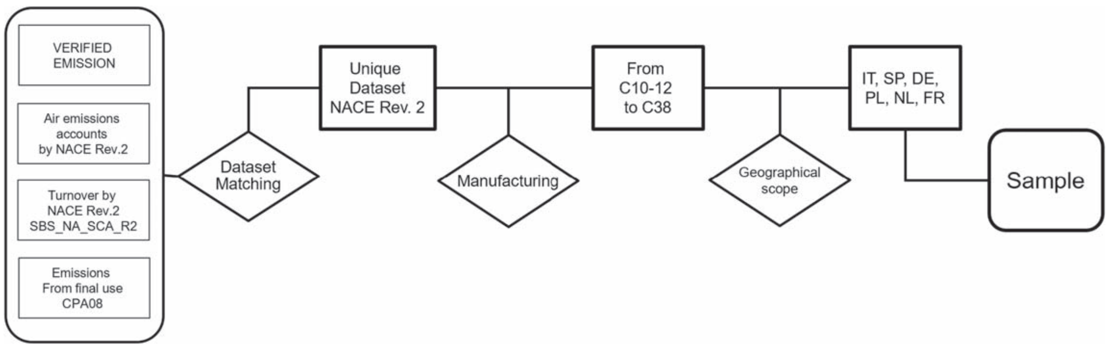

Figure 2. Sample definition process. Source: Own elaboration. DE: Germany, ES: Spain, FR: France, IT: Italy, NL; The Netherlands, PL: Poland.

Computer and similar, C27: Electrical equipment, C28: Machinery, C29: Motor vehicles, C30: Transport equipment, C31: Furniture, C33: Machinery and equipment.

The verified emissions, free allocation, and annual reconciliation of allowances were obtained from the European Registry of Installations, which records the installations covered by the ETS Directive. The total emissions by sector were obtained from the Air Emissions Account, whereas the turnover was obtained from the European Structural Business Statistics Database. The NACE Rev. Two criteria were used to aggregate and make the data comparable and suitable for our analysis. For each sector, it was possible to compare the share of emissions covered by the ETS on the overall emissions related to intermediate and final consumption. Figure 2 illustrates the dataset generation process.

To convert the registry's activity codes into NACE Rev. 2 codes, a transcode file was employed. This facilitated the alignment of emission data with air emission accounts and economic and trade data, thereby enabling the estimation of emissions imports and exports.

3.1. Variables

The variables have been chosen in light of the analyses carried out by the EU Commission in the impact assessment and aim to estimate the determinants of the ETS gap and to assess the relative effectiveness of the system. *GAP* is the target variable obtained by subtracting the verified emissions of the Union register from the total carbon dioxide generated by domestic demand. This variable measures the emissions determined by the domestic market not covered by the mechanism. *EXP* represents the total amount of carbon dioxide emissions from goods and services exported, whereas IMP represents the total amount of carbon dioxide emissions from goods and services imported. *ALL* is the total amount of free allocation provided to specific sectors by the ETS design. *CAR* is the ratio between verified emissions and turnover; it can be considered the carbon intensity of the sectors. *SIZE* is the ratio of the verified emissions of each sector divided by the total verified emissions of the country to which the industry belongs. Table 1 reports some descriptive statistics.

We considered the above-listed variables in light of the analyses conducted by the EU Commission in the Impact Assessment, which accompanies the Fit-for-55 package. Overall, our goal is to estimate the determinants of the ETS gap and, subsequently, use the estimated function to infer the relative effectiveness of the.

3.2. Data analysis

Linear panel models can be described through restrictions of the following general model as in equation (2), where $i = 1,\ldots, n$ is the group component, whereas $t = 1,\ldots,T$ is the time, and a random disturbance μ_{it} of mean 0, taking into consideration that μ_{it} is not estimable with $N = n \times T$.

$$xy_{it} = \alpha_{it} + \beta_{it}^{T} \quad x_{it} + u_{it} \tag{1}$$

Many assumptions are usually made about the parameters, the errors and the exogeneity of the regressors; the parameter homogeneity, which means that $\alpha_{it} = \alpha$ for all i,t and $\beta_{it} = \beta$ for all $i,t,$ is a commonly accepted assumption resulting in a linear model pooling all the data across i and t.

$$y_{it} = \alpha + \beta^{T} x_{it} + u_{it} \tag{2}$$

To model individual heterogeneity, one often assumes that the error term has two separate components, one specific to the individual and not changing over time. This is called the unobserved effects model shown in equation (3).

$$y_{it} = \alpha + \beta^{T} x_{it} + u_{it} + \varepsilon_{it} \tag{3}$$

The appropriate estimation method for this model depends on the properties of the two error components. The idiosyncratic error ε_{it} is usually assumed to be well-behaved and independent of both the regressors x_{it} and the individual error component μ_i. The individual component may be either independent of the regressors or correlated. Starting from the above consideration, the following model was set up as formalized in equation.

We estimated the following function in which the independent variable GAP should consider the relationship between carbon dioxide emissions and a set of variables xi with i = 1…., n, which are statistically significant in explaining the differences. Finally, equation (4) depicts the model.

$$GAP_{it} = \alpha + \beta_1 ALL_{it\,it} + \beta_2 EXP_{it} + \beta_3 \quad IMPt + \beta_4 CAR + \beta_5 SIZE_{it} + \varepsilon_{it} \tag{4}$$

After predicting the vector of the GAP according to equation (3), the residual vector was used as a proxy for measuring the system's effectiveness. More specifically, we first aggregated the data by year and sector to exclude biases due to annual variations; then, we calculated a vector of distances between residuals and ranked the data for benchmarking purposes. At the country level, we obtained the frontier by reclassifying the vector of distances.

Clearly, the research approach also has some limitations due to the necessity of inferring emission data, given the comparability issues among NACE Rev. 2, Union Registry and CPA codes that correspond to up to two digital levels. Additionally, the computation of import and export of emissions faces approximability issues even though the carbon intensity of extra-EU imports was defined using the parameters obtained from carbon emissions of all countries published by the European Commission.

4. Results

The results based on equation (3) are summarized in table 2, and the model was estimated using a panel data random effect model. The estimated values of coefficients $\beta 1\ldots\beta 5$ in equation (3) are listed in table 2.

The results reported in table 2 are consistent with expectations. Indeed, the parameter associated with free allowances (-0.483^{***}) suggests that the larger the free allowances for installations of a given sector, the smaller the gap. In other words, the allowances reduce the cost of emissions for firms or plants at risk of relocation. The parameter related to extra-EU exports (-0.773^{*}) suggests that the gap tends to decrease as exports from a particular sector increase, so that the share of emissions accounted for by the ETS tends to align with total emissions. In contrast, the import parameter (0.928^{**}) indicates that the gap tends to increase when the level of imports increases; thus, the share of emissions accounted for by the ETS tends to diverge from actual emissions, as assumed. Finally, the effects of parameters related to emissions intensity (-0.0159^{***}) and the relative size of the sector in terms of emissions (-8.164^{***}) suggest that the more emissions-intensive a sector, the better the ETS can capture actual emissions by adjusting for emissions determined by consumption of goods and services.

Table 1. Descriptive statistics.

Variable	Scope	Mean	Std. dev.	Min	Max
GAP	overall	14.180	1.391	10.052	17.282
	between		1.429	10.806	17.211
	within		0.224	12.047	15.204
ALL	overall	12.80052	2.690	7.830	17.705
	between		2.728	7.859	17.659
	within		0.121	11.997	13.603
EXP	overall	12.739	2.420	0.593	17.090
	between		2.498	2.491	15.799
	within		0.369	9.639	17.477
IMP	overall	12.845	2.447	0.992	17.007
	between		2.551	1.391	15.986
	within		0.334	10.601	17.747
SIZE	overall	−7.615	2.839	−14.565	−1.239
	between		2.886	−13.906	−1.326
	within		0.130	−8.570	−6.785
CAR	overall	2.756	2.729	−3.875	8.178
	between		2.741	−3.715	8.022
	within		0.183	1.269	4.270

Source: Own elaboration. Values in logarithms.

Table 2. Regression analysis.

Variable	Label	Coefficients	SE
ALL	Free allowances	-0.483^{***}	−0.119
EXP	Extra-Eu export	-0.773^{*}	−0.439
IMP	Extra-UE import	0.928^{**}	−0.46
INT	Sectorial carbon intensity	-0.0159^{***}	−0.00153
SIZE	Relative size of the sector	-8.164^{***}	−0.282
	Constant (m)	7.349^{***}	−1.002
	Observations		533
	Number of id		107
	R^2	Overall	0.919
		Between	0.927
		Within	0.852
	Wald χ^2		1578.96

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Based on the results of the predictions made by equation (3), it was possible to derive the relative efficiency of the ETS in accurately determining the level of emissions for a country's sectors. The vector of residuals expresses the difference between the total emissions and the emissions accounted for by the ETS. This approach allows us to develop a measure of the relative efficiency of an ETS. Figure 3 shows the evolution of emissions and the relative performance of ETS application at the country level. Verified emissions have decreased over time, similarly, both the production and consumption perspectives have, on average, decreased, although at different paces. In contrast, the performance of the ETS in terms of its efficiency in allocating costs to polluters shows different trends.

Figure 4 shows the discrepancy in emissions accounting, where narrower gaps suggest more accurate ETS emissions accounting. The variance of this gap between the same sectors in different countries is primarily due to extra-EU imports of intermediate inputs. Consequently, consumers in regions with a larger gap might experience lower prices. However, these results are not due to efficiency gains driven by technological innovation. Where extra-EU imports are high, final prices can be lower because the carbon price in Europe differs in the way the costs of emissions are borne by the emitter or passed down the value chain.

This additional effect affects the intra-EU competitive dimension, as consumers' willingness to pay will be lower for products in countries with higher extra-EU imports than EU productions. For example, sectors such as C10-C12, C23, C24, and C29 exhibit a noteworthy gap irrespective of the country under consideration. However, in most instances, there is a significant degree of variability. This variability could potentially engender

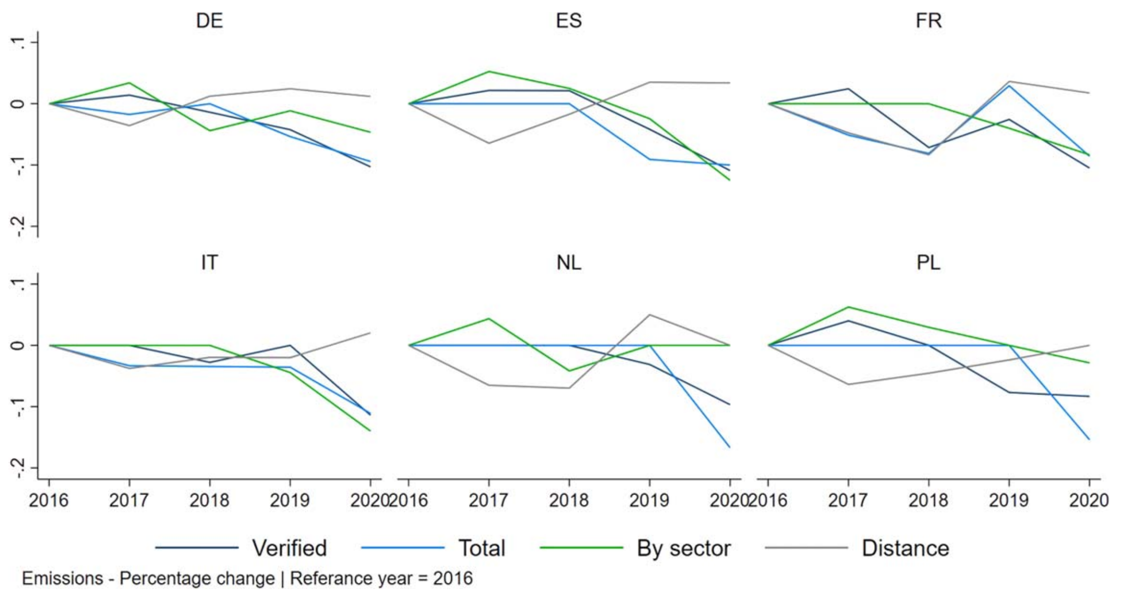

Figure 3. Trend in key emission variables and efficiency analysis. Source: Own elaboration.

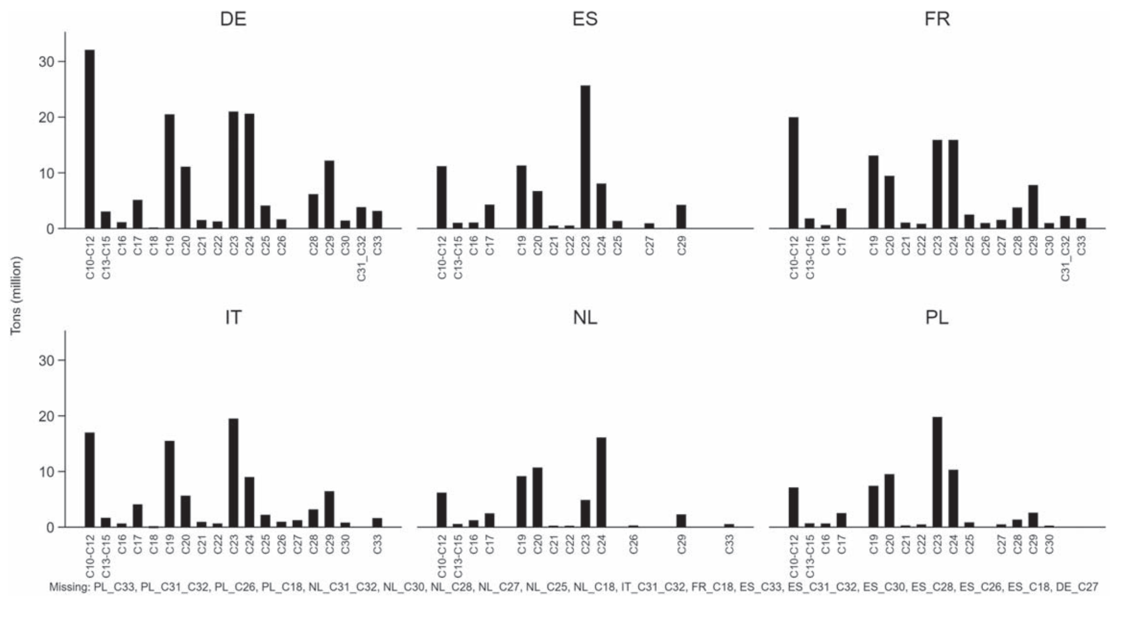

Figure 4. Average ETS gap across sectors. Source: Own elaboration.

issues concerning the level playing field. However, it must be noted that such interpretations are not linear. Indeed, the figures provided are contingent not only upon emission imports but are also influenced by the scale of the economy. Consequently, figure 4 should not be interpreted as a benchmark for cross-country comparison. For this reason, the mechanism must be accompanied by additional tools to correct distortions in the internal market to the detriment of European companies.

5. Discussion

The results are consistent with previous literature on the potential impact of ETS on the healthy functioning of the WU market given that our hypotheses are confirmed: When exports increase, the gap decreases, bringing the ETS in line with total emissions. Conversely, when imports increase, the gap widens and diverges from actual emissions. We constructed an ETS gap variable and showed discrepancies in the ability of the ETS to internalize costs across sectors, while the efficiency of the ETS in allocating costs to polluters showed different trends. The differential impact of the ETS also implies potential distortions in the productive sectors of the internal market. For consumers, costs could be lower due to higher extra-EU imports.

Our results also share some similarities with recent literature that analyzed the ETS effects retrospectively and observed that although the EU's emissions have steadily fallen thanks to ETS, anti-competitive issues have occurred [47]. Thus, we agree on the need for a complementary policy mix and tools to achieve decarbonization targets [48]. According to the European Parliament, changes in key areas are needed to update and make the ETS more efficient, including its capability to ensure safeguards against the risk of carbon leakage for the industry and promote low-carbon investments in Europe. Our hypotheses are confirmed specifically from table 2, from which it can be inferred that free allowances play a prominent role in making the system more efficient, as recently confirmed by a report of the European Court of Auditors that more targeted free allowances would have generated benefits for public finance and the proper functioning of the market [49].

Additionally, the role of exposition in extra-EU trade is confirmed. The results provide interesting implications regarding further policy measures in Europe, as they produce distorting effects that impact countries unevenly; a discussion on asymmetric regulation should be opened accordingly. In fact, problems persist in internalizing the environment of extra-EU productions that contribute to satisfying the final demand in the EU.

The higher the share of extra-EU imports, the higher the apparent benefit to consumers and intermediate goods importers, as they bear lower costs due to no or lower environmental compliance of such goods. However, total emissions are not reduced, and low-carbon investments are reduced because of environmental dumping.

Therefore, it is important to introduce mechanisms capable of pricing the externalities associated with emissions derived from demand homogeneously at the EU level to avoid discrimination by consumer and intermediate goods importers within the European single market. Concerning sectors, it is worthwhile to consider competition issues as per the potential distortion of the competitive playing field at the EU level. Emerging evidence in terms of the ETS gap between sectors of different countries is a valuable proxy for the distorting effects on the costs of emission externalities. Indeed, we discuss two types of emerging biases.

The first concerns the effectiveness of the ETS in safeguarding European industry from global environmental dumping. In terms of policy implications, this confirms the importance of introducing alternative mechanisms, such as CBAM, which a recent study suggests would reduce the risk of carbon leakage [50]. Nevertheless, the mechanism could have an unfair impact on the competitiveness of firms depending on their geographical location [51] and on their production specialization. Indeed, CBAM will initially apply to a limited number of products at risk of carbon leakage: in addition to electricity generation, iron, steel and aluminum, cement, and fertilizer. Provided that it is compliant with World Trade Organization trade rules, some scholars argue that the implications of CBAM could have important repercussions on poor countries in the event of a lack of support from more advanced economies [52]; these repercussions in the long run make international cooperation difficult. In addition, the application of CBAM to a limited number of sector risks alters the competitive dimension of the internal market, whereas a wider carbon taxation system may be cost-effective.

The second bias concerns the emergence of potential sectoral distortions at the EU level. The higher the gap is, the greater the competitive pressure on the sector due to the correlation between the emission coverage gap and competitive pressure given that, ceteris paribus, the same sectors in different countries are often characterized by a different degree of emissions covered by the ETS.

This study also has wider policy implications, as many countries have introduced market instruments to support investments aimed at reducing emissions by innovation in processes and plants through energy-efficient interventions [53]. For example, prominent market-based instruments are based on tradable certificates to support investments in energy efficiency [54] to help achieve decarbonization objectives, paving the way for efficiency gains [55]. However, the interaction between alternative policy instruments has also generated overlapping concerns with reference to the efficiency of the combined policy tools [56, 57].

This is confirmed by previous studies that have analyzed the risks and opportunities of the coexistence of different instruments to achieve environmental goals [38, 58, 59]. Nevertheless, combining complementary policy tools can also lead to positive outcomes.

6. Conclusion

The need to assess the effectiveness of the ETS in implementing the polluter pays principle and its efficiency in maintaining a level playing field within the EU inspired this study. We hypothesized that the mechanism struggled to properly allocate the costs of emissions, leading to potential inequities across industries and countries. Unlike earlier studies that focused on carbon leakage, our focus was on the potential distortion of competitiveness within the EU due to differences in the openness of manufacturing sectors outside the EU. We assessed the ETS's compliance with the polluter-pays principle and its ability to ensure a level playing field.

Our results confirmed an inverse relationship between the share of domestic demand met by extra-EU imports and the risk of environmental dumping for a given industry. This situation creates a competition issue, as industries and countries whose demand is largely met by extra-EU imports with lower standards gain a competitive advantage. Therefore, we concur with the necessity of introducing complementary mechanisms that effectively price carbon emissions.

The implementation of a carbon border adjustment mechanism is beneficial, but limiting its application to a reduced number of products could be inefficient; therefore, carbon taxation could also be a useful addition to address this issue. Future research should focus on finding an optimal policy mix that increases the likelihood of achieving multiple goals that are difficult to achieve with a single policy.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.5281/zenodo.7416573.

Competing interests

No competing interests.

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Ethics statement

This article does not report on or involve any animals, humans, human data, human issues or plants.

Authors' contributions

Both authors jointly contributed to the article.

Data

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