ENVIRONMENTAL STRINGENCY AND INTERNATIONAL TRADE: A LOOK ACROSS THE GLOBE

Abstract

This paper presents a novel analysis of the impact of environmental regulations aimed at reducing emissions in international trade in goods. Using a panel dataset of OECD, BRIC and other developing countries spanning from 2007 to 2018, we estimate a gravity model of trade using a Poisson pseudo-maximum likelihood estimator with high-dimensional fixed effects, controlling for potential confounding factors. Our empirical analysis integrates emissions intensity data with detailed international trade information at the industry level, considering both market-based and non-market-based environmental policies. We estimate models for aggregate and disaggregated trade flows, distinguishing between dirty and neutral industries, and among heterogenous countries. Our findings indicate that stricter environmental regulations tend to increase imports of goods, particularly those within highly polluting industries imported by high-income countries.

Key Words: Emissions and trade, Environmental policy, Pollution haven hypothesis, Gravity models, OECD

JEL: F18, H23, Q52, Q56, Q58

ENVIRONMENTAL STRINGENCY AND INTERNATIONAL TRADE: A LOOK ACROSS THE GLOBE

1. INTRODUCTION

The relationship between trade and environment is in the front line of today's policy debate. Trade liberalization, combined with the remarkable economic development in some regions and the fast-growing population, has resulted in an increasing use of natural resources and ever-rising pressure on the environment. As a result, in 2024 the concentration of carbon dioxide in the global atmosphere reached the highest level in 3 million years, posing a great threat to human health and even life (NOAA Earth System Research Laboratory). Furthermore, according to Copernicus (European Commission), 2024 was the warmest year on record globally, and the first calendar year that the average global temperature exceeded 1.5°C above its pre-industrial level. Global environmental pollution and climate change have the potential to limit sustainable development and damage human health. Hence, in order to mitigate undesirable effects, an active control of environmental pollution and climate change is crucial. This is arguably among the most urgent issues the world faces today. According to Andre et al. (2024), most people around the world (89 percent of those surveyed) demand more political action from their national governments. Thus, to achieve climate neutrality in 2050, countries worldwide are drawing up actions to reduce their greenhouse gas (GHG) emissions and many governments have actively implemented environmental regulations (Khalid et al., 2021).

As the green development agenda advances, environmental regulations are likely to play an increasing role in addressing the externalities of environmental pollution and correcting market failures. We are already witnessing this shift, as many countries have incorporated environmental considerations into their national and international legislation (Baghdadi et al. 2013; World Bank, 2023). Some of these actions are related to a progressive shift toward greener and cleaner economies, although this process has been proved to be unequal across countries. At the same time, international trade has been increasingly considered a driver of economic development (Frankel and Romer, 1995; Irwin and Terviö, 2010; among others), forming a central part of countries' development strategies (see Lewer and Berg, 2003; and Singh, 2010; Irwin, 2024; for surveys). Nevertheless, in todays' world of trade-driven development, environmental degradation could accelerate unless environmental measures are implemented at both domestic and international level. First, because trade is an important source of greenhouse gas emissions and second, if there is no international cooperation there is a risk that polluting activities will just be transferred to countries/regions with less stringent environmental standards, ultimately generating an increase in global pollution though so-called “carbon-leakage”[1]. Hence, it is essential to integrate environmental regulations into the trade policy framework to reassess and transform trade’s contribution to development and resolve potential conflicts with sustainable development (Coperland and Taylor, 2004; Barros and Martinez-Zarzoso, 2022).

In this context, the question of whether more stringent environmental regulations influence trade is highly relevant to the ongoing debate on advancing environmental regulation standards, especially in relation to trade patterns and trade agreements. This is especially a concern in developed countries since this shift towards green policies could induce firms to relocate part of their production in countries with laxer environmental requirements to evade pollution abatement costs. This relocation will contribute to creating “pollution havens” and undermine global efforts to reduce carbon emission and mitigate climate change (Dechezlepretre and Sato 2017, Cherniwchan, Copeland and Taylor 2017, Carril and Milgram 2024). To the best of our knowledge, this issue has not been fully studied in the literature[2], in particular using disaggregated sectoral trade data to look across sectors and types of goods, dirty and neutral, and also considering the level of development of the trading partners.

Previous empirical studies that tested the so-called pollution haven hypothesis (PHH) are far from unanimous, as indicated by Cole et al. 2017 and Dechezlepretre and Sato 2017. Studies focused on investigating the PHH are conducted though the lances of foreign direct investment (FDI) and location of production or are focusing on a single country (or a small subset of countries) and often use aggregated data. In this regard, focusing on a specific host country(s) presents a narrow(er) view, while separating specific focus industries according to their pollution intensity can lead to biased results due to other industry-specific trends. In general, studies tend to find mixed evidence of the existence

[1] For a review on carbon leakage see Jakob (2020).
[2] An exception is Rocha et al. 2024, who also uses disaggregated trade data but focus exclusively on the role of environmental provisions on trade agreements.

of the PHH and tend to conclude that environmental measures play a minor role in attracting FDI or driving trade flows (Carril and Milgram 2024, Levinson, 2023).

The reasons behind the inconclusiveness of the findings for the PHH can be the distribution of trade patterns across the world (as most trade is done between developed countries), the likelihood of mobility of an industry and the associated abatement costs, as well as, the use of aggregate trade data in the analysis, the multidimensionality issues in measuring environmental stringency and the endogeneity of policies or the unobserved or unaccounted for industry characteristics (Ederington et al., 2005, Brunel and Levinson 2016, Copeland, Shapiro, and Taylor 2022). Levinson (2023) also indicates that it is tricky to identify the cause-and-effect relationship of whether regulations in developed countries cause polluting industries to relocate to pollution havens. He argues that "for all the talk of outsourcing pollution in the media and politics, there is surprisingly little empirical evidence that high-income regions increasingly and disproportionally import products of the most polluting sectors". One reason for this he argues, is that detailed industry-specific emissions intensities are not available for most countries.

Against this background, as more and better data is available, it is now possible to use larger samples, more disaggregated data and more advanced econometric approaches to re-examine this important question. Hence, our contribution to the literature on international trade and environmental regulations is three-fold. First, this paper seeks to examine whether stringent environmental regulations affect trade patterns, potentially creating competitive advantages for countries with less stringent regulations, using disaggregated sector-level data for a large sample of countries, by merging datasets of emissions intensities per industry with various environmental policy variables. Secondly, we examine the nexus between trade and environmental regulation using several measures of environmental stringency, in an attempt to deal with the multidimensionality issues in measuring environmental stringency. Finaly, we seek to investigate how the relationship between environmental stringency and trade varies across industries based on their pollution intensity (dirty vs. the rest) and the development status of trading partners. In addition, we go a step further and use the latest econometric approaches in estimating gravity models of trade using a Poisson pseudo-maximum likelihood (PPML) estimator with high dimensional fixed effects, (Correia, Guimaraes and Zylkin, 2020), which accounts for several sources of unobserved heterogeneity helping to identify causal effects.

Our results show that, irrespective of the environmental stringency variable used or the development level of the trading partners, pollution control measures lead to an increase in imports from countries with laxer environmental regulations (thus having a detrimental effect on local firms' competitiveness). This impact is especially pronounced in industries characterized as dirty or highly polluting and its magnitude varies in terms of measure of environmental stringency applied and analyzed. From a policy perspective, these findings can be highly relevant in the current debate on advancing environmental regulation standards, especially in relation to trade patterns and latest spur of protectionist measures, or the upcoming roll-out of the European Union's Carbon Border Adjustment Mechanism (CBAM) expected to begin collecting payments in 2026[3].

The remainder of the paper is structured as follows. Section 2 provides an overview of the related literature and theoretical background. In section 3 we provide stylized facts examining the relation between environmental stringency and trade. In section 4 we present the model and provide explanations on the different variables. Section 5 presents the main results and section 6 concludes, providing policy options along the way.

2. LITERATURE REVIEW

Trade as an important economic activity is inevitably producing GHG emissions. Therefore, the impact of trade on the environment has been capturing ever-rising interest by scholars in recent decades (Cherniwchan et al., 2017). How environmental policies might affect trade has been the subject of considerable debate, from neoclassical approach (Tobey, 1990, Grossman and Krueger, 1991) to the "competitiveness school" approach (Mulatu, 2018). Following the seminal work by Grossman and Krueger (1991) scholars had typically decomposed the environmental impact of trade liberalization into scale, technique, and composition effects (Antweiler, Copeland, and Taylor, 2001). It has been noted that these three elements are simultaneously present under a liberalized trade regime.

The scale effect captures how the expansion of economic activity due to trade leads to a larger environmental footprint, when keeping constant the composition of goods

[3] The United Kingdom plans to implement a CBAM starting in 2027. Canada, Japan, and the United States have considered similar measures.

produced and the production technologies. In most cases, the increased economic activity –driven by reductions in trade barriers –leads to greater use of natural resources, more waste, and higher levels of pollution. Nevertheless, the scale effect is not that straightforward, since an increased economic activity also leads to a higher demand for environmental quality and a reduction in emissions, in line with the environmental Kuznets curve (Dinda, 2004, Martínez-Zarzoso and Maurotti, 2013, Stern, 2017, among others), incentivizing companies to match this demand by introducing higher environmental standards and selling cleaner goods (Copeland and Taylor, 2004; Grossman and Krueger, 1991).

The composition effect is linked to the comparative advantage theory, but as with the scale effect its impact is ambiguous. With trade liberalization, countries specialize in producing goods for which they have a comparative advantage. In this regard, the mix of industries within a country is expected to change, which can have significant environmental consequences. For example, if a country specializes in pollution-intensive industries, the overall environmental quality could worsen. Conversely, if a country shifts towards less pollution-intensive industries, environmental quality could improve. The composition effect highlights how trade can alter the environmental footprint by changing the industrial mix of an economy.

Finally, the technique effect describes changes in production methods and technologies due to trade liberalization. When countries open up to trade, they often gain access to more advanced, cleaner, and more efficient technologies, that may reduce environmental degradation. Assuming that the scale of output, and composition of production does not vary, an improvement in the technique can mitigate some of the negative environmental impacts by promoting cleaner production methods. Two predominant theoretical hypotheses related to the relationship between trade and the environment have emerged from these effects: The Porter hypothesis and the pollution haven hypothesis[4].

The Porter hypothesis takes a dynamic view stating that stringent environmental policies can improve competitiveness of companies and thus stimulate trade, through a reduction of production costs fostered by innovation that leads to an efficient use of resources (Porter, 1991, Porter and van der Linde, 1995a). The underlying idea is that, in a country

---

[4] Apart from the pollution haven and the Porter hypothesis, some authors have introduced the race to the bottom and the endowment hypothesis, but they are in essence linked or derived from the former two.

with high environmental regulatory stringency, companies will be faced with relatively high production costs, which affects their competitiveness. This will put pressure on companies and incentivize them to innovate and produce cleaner goods. If these innovations lead to input cost reductions (like energy, for example) this can partly offset the initial higher environmental compliance costs. Thus, the Porter hypothesis views environmental policies as stimulus for new products and processes, thanks mainly to market instruments i.e. Porter's "weak" hypothesis.

Porter and van der Linde (1995a) go even further in the so-called "strong" version of the hypothesis, stating that stricter regulation enhances business performance and these cost-cutting technologies in turn could completely offset regulatory costs, and foster innovation in new technologies that may help firms achieve international technological leadership and expand market share. In this sense, the Porter hypothesis postulates that a country can generate a first-mover advantage to domestic companies by regulating pollution sooner than other countries, which leads domestic firms toward international competitiveness in markets with growing demand for environmentally friendly products and services (Rivera and Oh, 2013). Furthermore, this may induce a "greening" transfer of both environmentally friendly technology and management practices (Poelhekke and Van der Ploeg, 2015, Jin et al., 2019), which could improve environmental standards, contributing to creating a "pollution halo" effect (Zugravu-Soilita, 2017).

Evidence for the weak version of the Porter hypothesis is fairly well established, with most of the existing studies supporting the Porter hypothesis and believe that environmental regulation has positive significance for the green technological innovation (Jaffe and Palmer 1997, Brunnermeier and Cohen 2003, Rubashkina et al. 2015, Fabrizi et al. 2018, Martinez-Zarzoso et al. 2019, De Santis et al. 2021). On the other hand, the empirical evidence on the strong version is mixed. There are studies that do not support the hypothesis, such as (Rubashkina et al. 2015 and Nie et al. 2021), and studies that confirm it, such as (Costantini and Mazzanti 2012 and Martínez-Zarzoso et al. 2019, Wang et al. 2019a,b, Yang et al. 2020, De Santis et al. 2021).

The pollution haven hypothesis on the other hand, predicts that, driven by the intention to reduce their production costs, stricter environmental regulations induce pollution-intensive industries to migrate to less regulated countries. This creates "pollution havens" in countries with lax environmental regulations and cause policy-induced pollution leakage, leading to increased pollution in those regions, while environmental quality improves in countries with higher environmental standards. (Copeland and Taylor, 1994; Ulph 1998, Levinson and Taylor, 2008).

The existence of pollution haven effects has been empirically analyzed both in the context of international trade and FDI. Early empirical papers revert to a Heckscher-Ohlin (HO) type of model, where revealed comparative advantages are explained by factor endowments, suggesting that the stringency of environmental regulations had little or no impact on trade patterns (Jaffe et al. 1995, Grossman and Krueger, 1995, Tobey, 1990, Xu, 2000, Ederington and Minier 2003, Grether and de Melo, 2003). Much of this work used cross-sectoral data and the results were influenced by omitted variables bias and failure to deal with endogeneity.

Over the past decade, the proliferation of environmental policies worldwide has enhanced compliance measurement and data availability. This has sparked renewed interest and enabled more detailed empirical analyses of the socio-economic effects of asymmetric environmental policies. In what follows we summarize exclusively the papers that analyzed trade flows, which is the focus of this paper[5].

Some studies focus on specific country pairs or country groups. For instance, López et al. (2013) found strong evidence for the support of the pollution haven hypothesis from the analysis of bilateral trade between Spain and China. They found that China has become a pollution haven for energy intensive industries of Spain. Similarly, analyzing the US-India trade link, Sawhney and Rastogi (2015) concluded that a decade of trade liberalization had made India a pollution haven for some polluting industries of the USA like chemical, steel, and iron. Gani (2013) also found that trade and industrial activities have a strong impact on pollution in Arab states.

Taking a broader perspective, Chakraborty and Mukherjee (2013) investigate the pollution haven hypothesis using a sample of 114 countries. They supported the hypothesis from the analysis of trade and environment nexus for the period of 2000–2011 using an environment performance index as a measure of pollution. They found that export of primary and manufactured goods of developing countries has caused

[5] The PHH has also been analyzed from the angle of FDI flows from developed to developing countries. For a review of this branch of the literature please see Cole et al. 2017, Paul and Benito 2018 or Carril-Caccia and Baleix, 2024.

environmental degradation in these countries. Duan et al. (2021) suggest that high-income countries offshore their emissions to low-income countries by outsourcing only the dirty production stages instead of the entire production process, and that global value chains are also “global pollution chains”. Similar results are reported by Peiró-Palomino et al. (2022) using institutional quality measures for a set of 140 countries. Moreover, Copeland, Shapiro, and Taylor (2022) use a multi-region input output tables to approximates how much pollution was caused in developing countries as a consequence of their exports. They conclude that rich countries are increasingly outsourcing pollution, based on their finding that pollution embodied in rich-country imports is larger than pollution embodied in rich-country exports, which is consistent with richer countries having stricter pollution standards and using cleaner production technologies, even for the same goods.

Conversely, some studies have disputed these empirical findings, concluding that the PHH either does not hold true or is only valid in certain cases. For example, Cole and Elliott (2003) examined north-south trade data and the possible impact of these trade flows on water and air pollutants in developing countries, concluding that there is a relatively small role of pollution haven effects as compared to other explanatory arguments. Kearsley and Riddel (2010) also suggested that no significant correlation exists between per capita GHG emissions and trade openness. Similarly, Rasit and Aralas (2017) examine ASEAN countries in the period 2000–2010 and conclude that the pollution haven hypothesis is not valid for the countries in question. Kathuria (2018) examines the case of India and also finds no evidence for the pollution haven hypothesis for trade. Balsalobre-Lorente et al. (2019) come to the same conclusion for Mexico, Nigeria, Indonesia and Turkey, while Shao et al. (2019) obtain similar findings for the BRIC countries. Finally, Levinson (2023) looked at the question of whether developed countries outsource pollution from various angles and comes to mixed conclusions. He argues that there is no evidence that developed countries cleaned their own environment by importing polluting goods. On the question of whether developed countries imports resulted in more pollution elsewhere, his conclusion is that it depends on the industry and on the (diss)aggregate data used in the analysis. On the question of whether regulations in developed countries cause polluting industries to relocate to pollution havens, he argues that for specific polluting industries examples can be demonstrated, but indicates that this is tricky if not analyzed through disaggregated data.

In general, whether the pollution haven effect or pollution halo effect predominates remains an empirical question with discrepant answers. As per the abovementioned literature, there is no consensus among scholars regarding the links between environmental regulations and international trade. The pollution haven hypothesis appears to be valid in certain countries, industries and research periods, and dependent on the type of environmental policies and industrial characteristics in those countries, as well as the granularity level of analysis. Thus, in this paper, we attempt to shed further light on this topic by providing a broader view on the subject and attempting to fill in identified research gaps.

Scholars have highlighted various reasons which might explain why some studies do not support the pollution haven hypothesis. They range from, the distribution of trade patterns across the world (as the lion's share of world trade takes place between developed countries), the likelihood of industry mobility and the associated proportion of total production costs, the use of aggregate trade data in the analysis, or the focus only on one measure of environmental stringency and the endogeneity of policies and unobserved or unaccounted for industry characteristics (Ederington et al., 2005, Brunel and Levinson 2016, Copeland, Shapiro, and Taylor 2022, Levinson 2023)[6]. For this reason, in our study, we test both aggregate and disaggregated trade data to account for these potential shortcomings, using disaggregated sector-level data for a large sample of countries. Moreover, we do this for a broad range of countries (developed and developing) and incorporate various measures of environmental stringency, to deal with the multidimensionality issues in measuring environmental stringency. In addition, we go a step further and borrow from the international trade literature the latest econometric approaches in estimate gravity models of trade using a Poisson pseudo-maximum likelihood (PPML) estimator with high dimensional fixed effects, (Correia, Guimaraes and Zylkin, 2020).

3. DATA, VARIABLES AND SYLIZED FACTS

In this section, we present the data sources, and the variables used (subsection 3.1) and some stylized facts for environmental policy stringency (subsection 3.2).

[6] Recently Copeland, Shapiro, and Taylor 2022 argued that it is also important to come to conclusion on the magnitude of the impact of the pollution leakage, but this is outside of the scope of this work.

3.1. *Data and Variables*

The main dependent variable is bilateral trade (imports and exports) and the target variables are four proxies for environmental policies, namely, carbon pricing policies (a dummy variable for the existence of an emissions trade system -ETS), environmental taxes on carbon and energy and an index that comprises both market and non-market price mechanisms. Trade values are from the Balanced International Merchandise Trade Statistics from the OECD. Bilateral exports and imports are measured in currents US $. The carbon pricing and ETS variables are constructed using data from the World Bank Carbon Pricing Dashboard. Revenues from carbon and energy taxes as a percent of GDP, the environmental policy stringency (EPS) index and its different dimensions are from the OECD. The EPS index is a country-specific and internationally comparable index of the stringency of environmental policy. Stringency is defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior. Emissions intensities are obtained from the OECD inter-country input-output trade of CO_2 emissions embodied in international trade database. Table 1 presents the summary statistics of the main variables used in the empirical analysis[7].

Table 1. Summary statistics of the main variables

Variable	Obs	Mean	Std. dev.	Min	Max
Bilateral imports	418,842	2.11E+08	1.25E+09	0.49	1.09E+11
Bilateral exports	402,169	2.22E+08	1.31E+09	0	1.07E+11
Carbon Price Reporter	418,842	0.15	2.23	0	220
Carbon Price Partner	418,842	0.11	1.75	0	220
Envir. Tax. Reporter	417,599	0.43	10.01	-1.54	1021
Envir. Tax. Partner	396,646	0.40	8.12	-1.54	1021
Tax Energy Reporter	417,599	0.33	8.15	-1.77	834
Tax Energy Partner	396,646	0.30	6.62	-1.77	834
EPS Reporter	375,920	0.51	6.82	0	648
EPS Partner	303,510	0.51	6.03	0	648

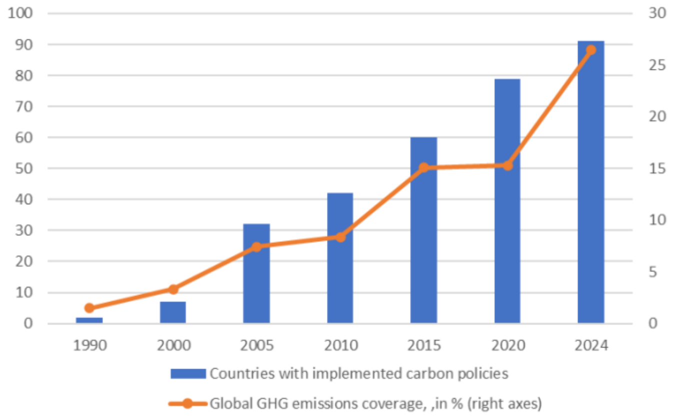
Note: EPS denotes environmental policy stringency index.

[7] For more detail on the data sources see Table A.1. in the Appendix.

3.2. *Stylized Facts*

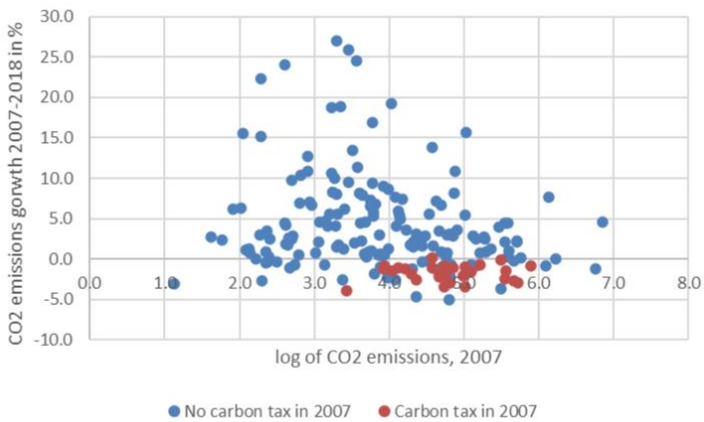
In this subsection we present several figures that illustrate the adoption over time of environmental policies and their effect on CO_2 emissions. Figure 1 shows the global evolution of carbon pricing policies, revealing a clear upward trend in their implementation over time. Since the first carbon tax was introduced in Finland in 1990, the number of countries that have implemented a carbon pricing policy has been growing rapidly. By 2024, 91 countries had a carbon price at either the national or subnational level, covering around 26 percent of global GHG emissions (World Bank 2024).

Figure 1. Number of countries with implemented carbon pricing policies from 1990 to 2024



Source: Authors elaboration using data from the World Bank.

Figure 2. Annual average CO_2 emissions growth and log CO_2 emissions over the period 2007-2017

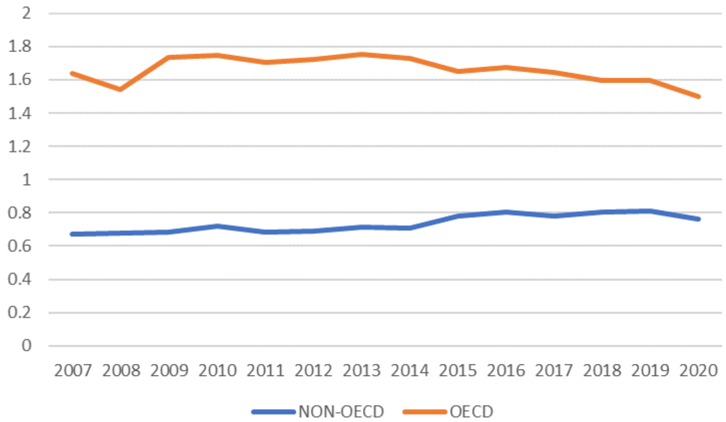


Source: Authors elaboration using data from the World Bank.

Figure 2 shows the average annual growth in CO_2 emissions over the period 2007–2018 against the logged level of CO_2 in the first period, distinguishing between countries with a carbon tax or price in 2007 (red) and those without this environmental policy (blue). We can observe that the countries without a carbon taxor price in 2007 (blue), have actually increased their CO_2 emissions growth rate vis-à-vis the initial level, on average by 4.4 percent per year (with some exceptions as evident on the chart). On the other hand, for the countries that did have a carbon tax or an ETS in 2007 (red) their CO_2 emissions growth rate has decreased by an average of 1.7 percent per year.

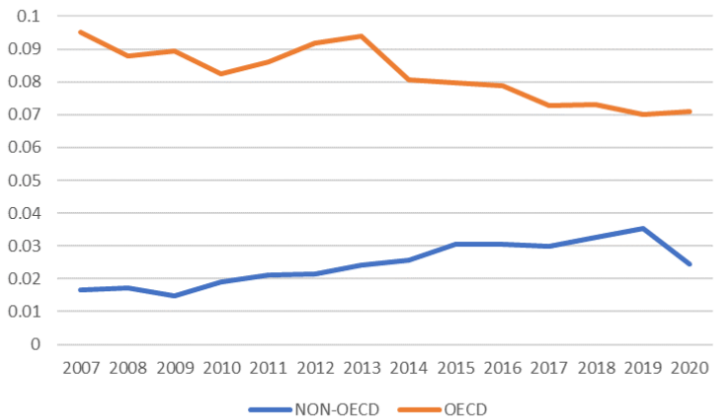
Figure 3 and 4 show the evolution over time of energy and CO_2 taxes, respectively, as a percent of GDP for the period 2007-2018, distinguishing between OECD and non-OECD countries. For OECD countries, there is a gradual convergence toward lower average values, possibly indicating a shift to cleaner production processes that are taxed less. Conversely, for non-OECD countries we can appreciate a slight increase in environmental taxes (the decline in 2020 is due to the COVID-19 effect). This likely indicates an increase in the tax base intensity, as new environmental taxes are being introduced in these countries.

Figure 3. Taxes on Energy (including fuel for transport), as percent of GDP



Source: Authors elaboration using data from OECD Environmentally Related Tax Revenues.

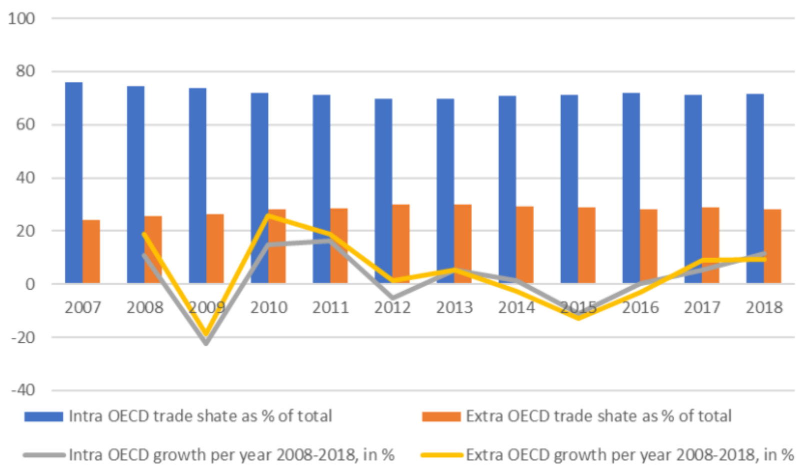
Figure 4. Taxes on Pollution, as percent of GDP



Source: Authors elaboration using data from OECD Environmentally Related Tax Revenues.

Beyond the environmental aspect, we must also examine trade dynamics. Figure 5 shows the evolution of intra-OECD and extra-OECD trade over the period under analysis, showing the annual growth rate of trade and the share of intra- and extra-OECD trade. On average, OECD countries have experienced an annual increase of approximately 10.7 percent in nominal terms during the period 2007-2018. Nevertheless, trade with non-OECD countries increased more than intra-OECD trade. Specifically, trade with non-OECD countries increased by over 12 percent per annum, while intra-OECD trade increased by 10 percent annually. Still, trade with non-OECD countries (extra-OECD) increased from a much lower base. Moreover, as can be seen, the share of intra-OECD trade is much higher compared to trade with non-OECD. In 2018, the former one was just over 70 percent of total trade of OECD countries, declining slightly from 76 percent in 2007. In contrast, the share of trade with non-OECD countries stood at just under 30 percent in 2018, increasing from 24 percent in 2007.

Figure 5. Annual trade growth rate and shares of OECD and Non-OECD countries, 2007-2018, in %percent



Source: Authors elaboration using data from OECD Environmentally Related Tax Revenue

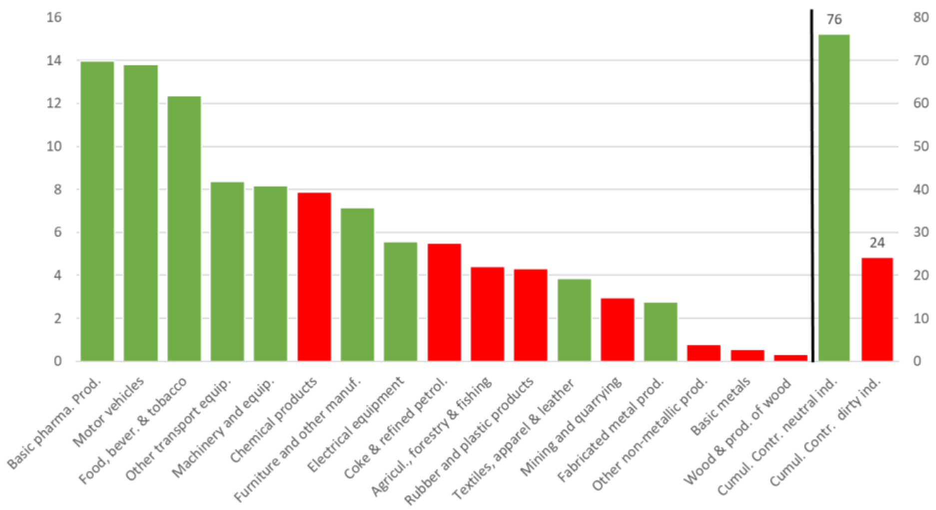
In Figure 6 we show the contribution to trade growth of OECD countries by industry. For comparison, we have divided the industries between dirty (red) and the rest, that we denote neutral all over the paper[8] (for more details see Table A.2. in Appendix). This allows for an analysis of which type of sectors have contributed the most to growth and which have had a smaller impact. Figure 6 (a) shows that intra-OECD trade growth has

[8] The distinction between dirty and neutral products is done using the average CO_2 emissions per industry as a separation line. The classification is similar to other studies like Kozluk and Timiliotis (2016) and Bauckloh et al. (2022).

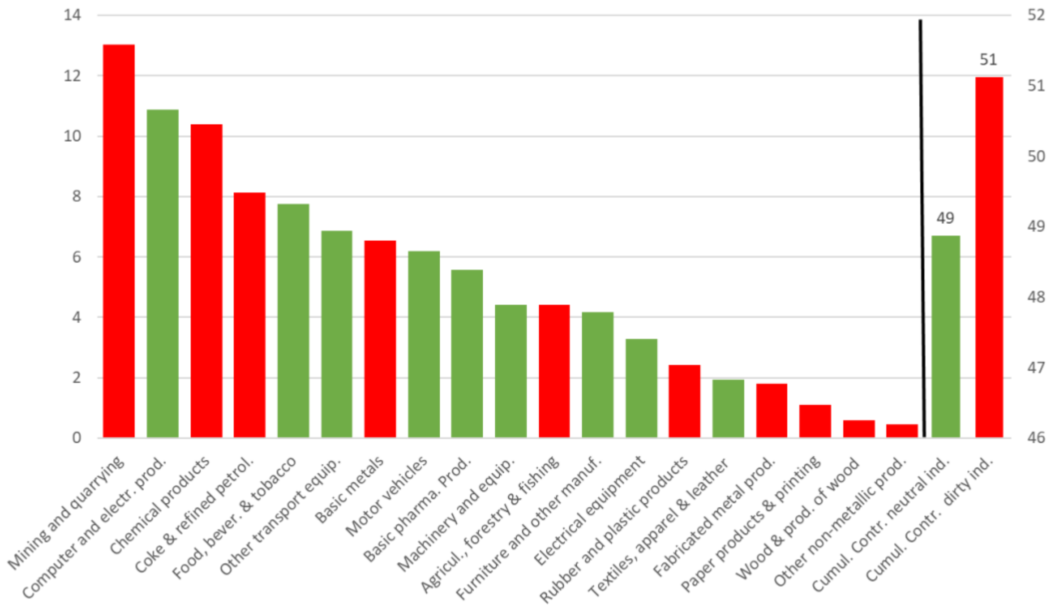
been largely driven by neutral industries with pharmaceuticals, motor vehicles, food and beverages, transport and machinery equipment, leading the way and accounting for almost two-thirds of growth (as shown in the cumulative values to the right of the vertical line in the chart). This indicates that less pollution-intensive goods are mostly traded (might have a comparative advantage) among these countries, with relatively similar environmental standards, whereas the contribution to growth in trade of dirty industries has been smaller accounting for 24 percent. Conversely, as can be appreciated in Figure 6 (b), most of extra-OECD trade growth over the sample period 2007-2018 is attributed to dirty industries, representing just over half of overall trade (as shown in the cumulative values to the right of the vertical line in the chart). Specifically, industries such as mining, chemicals, coke and petroleum and basic metals contributed over 38 percentage points to this growth.

Figure 6. Contribution to growth of neutral and dirty industries, 2007-2018

(a) Intra-OECD



(b) Extra-OECD



Source: Authors elaboration using data from OECD International Merchandise Trade.
Note: Neutral industries are colored green and dirty ones are red.

In summary, the presented stylized facts suggest that environmental regulations are becoming increasingly more important in a growing number of countries, including both OECD and non-OECD countries. Moreover, since a rising number of emerging economies (lead by BRICS) and some developing countries are implementing environmental regulations, some convergence of environmental taxes among developed and developing countries is observed. A first graphical analysis shows that countries with environmental regulations enacted earlier in time tend to have lower CO_2 emissions. Furthermore, within OECD countries, the growth in intra-OECD trade is predominantly driven by neutral industries, whereas extra-OECD trade growth is largely fueled by dirty industries. This observation tentatively supports the PHH, suggesting that OECD countries may import more goods in polluting industries from non-OECD countries. However, we cannot ignore that other factors and potential measurement errors might also influence this relationship. Additionally, it is crucial to determine the direction of this causal relationship. To deal with these issues, in the next section we present an in-depth econometric analysis, which takes into account relevant covariates, and control for unobserved heterogeneity at various levels using panel data techniques.

4. THEORECTICAL BACKGROUND AND MODEL SPECIFICATION

The gravity model of trade is nowadays the most accepted framework to model bilateral trade flows and to quantify the effects of trade and regulatory policies (Anderson, 1979, Bergstrand, 1985, Anderson and Van Wincoop, 2003). Irrespective of the theoretical framework of reference, most of the mainstream foundations of the gravity model are variants of the Anderson (Anderson, 1979) and Bergstrand (Bergstrand, 1985) demand-driven models, which assumes a constant elasticity of substitution and product differentiation by origin. The underlying theory indicates that trade between two countries is explained by nominal incomes, by the distance between the economic centers of the exporter and importer and by trade costs usually proxied with several trade impeding and trade facilitating variables, such as trade agreements, common language, or a common border.

The gravity model assumes constant elasticity of substitution and product differentiation by place of origin. In addition, prices differ among locations due to symmetric bilateral trade costs. According to Anderson and van Wincoop (2003), who reformulated and extended the theory, and adding the time and sectoral dimensions, the specification of the model is given by,

$$X_{ijkt} = \frac{Y_{it}Y_{jt}}{Y_t^W}\left(\frac{t_{ijt}}{P_{it}P_{jt}}\right)^{1-\sigma} \qquad (1)$$

where X_{ijkt} are bilateral imports (exports) of product k from country i to country j in year *t*, and Y_{it}, Y_{jt} and Y_t^W are the GDPs in the exporting country, the importing country, and the world in year *t*, respectively. t_{ijt} denotes trade cost between the exporter and the importer in year t, and P_{it} and P_{jt} are the so-called multilateral resistance terms (MRT). σ is the elasticity of substitution between goods. The empirical specification of the model in log-linear form is given by,

$$\ln X_{ijkt} = ln\ Y_{it} + ln\ Y_{jt} - \ln Y_t^W + (1-\sigma)\ln t_{ijt} - (1-\sigma) ln\ P_{it} - (1-\sigma)\ln P_{jt} \qquad (2)$$

The estimation of equation (2) is not straightforward, since some assumptions are required concerning the trade costs and MRT. The trade cost function is assumed to be a linear function of trade barriers, namely the time invariant determinants of trade flows such as distance, common border, common language and whether a country is landlocked. Substituting the trade cost function into equation (1) and adding the error term suggests estimating the following model:

$$\ln(X_{ijkt}) = \alpha_0 + \alpha_1 \ln Y_{it} + \alpha_2 \ln Y_{jt} + \alpha_3 ln\, D_{ij} + \alpha_4 Land_i + \alpha_5 Land_j + \alpha_6\, Border_{ij} + \alpha_7 Lang_{ij} + \alpha_7 Colony_{ijt} + u_{ijkt} \quad (3)$$

where D_{ij} denotes geographical distance from country i to country j, $Land_i$ and $Land_j$ take the value of one when countries i or/and j are respectively landlocked, zero otherwise, $Border_{ij}$ takes the value of one when the trading countries share a border, zero otherwise, $Lang_{ij}$ takes the value of one when the trading countries share a common language, zero otherwise and $Colony_{ij}$ when they have or had in the past a colonial link. An idiosyncratic error term is denoted by u_{ijkt}.

Based on the recent gravity literature, the MRT are modeled as origin-time and destination-time specific dummies. Moreover, according to Baier and Bergstrand (2007) and many others thereafter, country-pair-specific dummy variables that account for unobserved heterogeneity that is time invariant and specific to each trading relationship, mitigates endogeneity issues. Their addition to the empirical model prevents us from obtaining the coefficient estimates for time-invariant variables, and their effects are subsumed into the country-pair dummies.

The gravity model has been widely used to investigate the role played by specific policy or geographical variables in explaining bilateral trade flows. Consistent with this approach, and in order to investigate the effect of environmental regulations on trade, we augment the model with the different environmental regulations in the reporter (OECD) and partner countries (OECD or non-OECD) and use bilateral imports of OECD countries as the main dependent variable. Since these variables are country-specific we interact them with the energy intensity at the sectoral level, as our dependent variable is industry-specific. We also estimate the model excluding the agriculture sector and not centering the emissions intensity variable, as robustness check. Introducing four sets of fixed effects, the specification of the gravity model is given by:

$$\ln\left(X_{ijkt}\right) = \alpha_0 + \alpha_1\,(EI * EnvPol)_{ikt} + \alpha_2\,(EI * EnvPol)_{jkt} + \theta_{it} + \lambda_{jt} + \delta_{ij} + {} + \pi_{kt} + \varepsilon_{ijkt} \quad (4)$$

where, X_{ijkt} is imports (exports) of industry k from country i to country j at time t; and environment stringency ($EnvPol$) is proxied by the interaction of carbon emissions intensity (EI_{kt}) with four different environmental policy variables: $PCO2_{it(jt)}$ is a dummy variable with a value of one for countries that had implemented carbon pricing (either a carbon tax or an ETS) in year *t* and zero otherwise; $\ln EnvTax_{it(jt)}$ represents taxes on pollution and energy; $lnEPS_{it(jt)}$ is a country-specific and internationally-comparable measure of the stringency of environmental policy, where stringency is defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviour. The estimated model includes four sets of fixed effects: reporter-time (*it*); partner-time (*jt*); industry-time (*kt*) and reporter-partner (*ij*).

Despite the widespread use of the log-linearized gravity model, for estimation purposes we employed a consistent estimator designed for panel data, a Poisson pseudo-likelihood estimator, which includes high-dimensional fixed effects (PPML-HDFE) including *it*, *jt* and *ijk* dimensions. This approach combines the strengths of PPML estimators, which have clear advantages over OLS as outlined by Silva and Tenreyro (2006), with the capability to control for confounding factors using a routine developed by Correia (2020).

The PPML model specification is given by:

$$X_{ijkt} = \exp\big(\alpha_1\,[EI * EnvPol]_{ikt} + \alpha_2\,[EI * EnvPol]_{jkt} + \theta_{it} + \lambda_{jt} + \delta_{ij} + \\ +\pi_{kt}\big)\,\epsilon_{ijkt} \qquad (5)$$

where the defined variables are as in eq. (4).

5. RESULTS AND DISCUSSIONS

In this section the main empirical results are presented in (5.1) and a number of robustness checks are performed in (5.2).

5.1. Main Results

The main model has been estimated for bilateral imports, first pooling all industries and second for specific industries. Results from estimating specification (5) for all industries are presented in Table 2. Four different proxies for environmental policy stringency of the importer and exporters are introduced sequentially in the specification, each of them interacted with the CO_2 emissions intensity by industry and time. The results for carbon prices are shown in column (1), for environmental and energy taxes in columns (2) and (3), respectively and for the EPS in column (4).

Table 2. Main Results for Total Imports for the period 2007-2018

Dependent variable: Imports	(1) Carbon Price	(2) Envir. Taxes	(3) Tax Energy	(4) EPS
Explanatory variables:				
ES reporter*EI	0.027***	-0.054***	0.003	0.238***
	(0.003)	(0.020)	(0.004)	(0.027)
ES partner*EI	-0.114***	-0.061***	-0.011**	-0.324***
	(0.034)	(0.017)	(0.005)	(0.033)
Observations	496,851	293,312	307,283	288,278
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The estimated coefficients indicate that the introduction of a carbon price and an increase in the environmental policy stringency index of the importing country have positive and significant effects on imports, whereas an increase in environmental taxes is associated with decreasing imports. A positive coefficient associated with the environmental regulation variables aligns with the theory, suggesting that more stringent environmental policies lead to an increased import of dirty goods. Conversely, greater environmental policy stringency in the partner country is associated with a decline in imports in the reporter country, as expected. It is important to remark that the policy variables have been interacted with the average industry emissions intensity (EI) of the importing country, meaning that we quantify the effect of an increase in stringency for industries with EI above the mean. In this sense, a 10 percent increase in environmental stringency in the reporter country (assuming the same emissions intensity) would lead to an increase in imports of dirty goods in the range of 0.27 (column 1) and 2.38 percent (column 4), depending on the environmental policy. The same 10 percent increase in environmental stringency (assuming the same emissions intensity) in the partner country (exporter) would lead to a decline in imports in the reporter country (a decline in exports from the partner country) in the range of 1.14 (column 1) and 3.24 percent (column 4).

As mentioned before, and highlighted as a gap in related literature, to obtain a full picture, and given the multidimensionality of environmental policy and its consequences, it is important to consider heterogeneous effects that the development status of a country might have. This is of particular importance for the pollution haven hypothesis, given that it predicts that there will be a shift of production from countries with more stringent environmental laws (developed countries) to countries with less stringent ones (emerging and developing countries).

Thus, in Table 3 we consider the development level of the trading countries, and we report the estimated coefficients for the policy variables allowing for heterogeneity between OECD and non-OECD trading partners. In columns (1) and (4) the results show that the estimated coefficients of (carbon prices*EI) and of the EPS*EI of the importer are of similar magnitude for OECD and non-OECD partners, and not statistically different. In columns (2) and (3) the results are mixed and some unexpected negative associations are found between OECD imports and environmental taxes in the case of intra-OECD trade and between imports and energy taxes when trading with non-OECD countries.

Table 3. Trading Partners' Heterogeneous Effects by Development Level

Dependent variable: Imports	Carbon Price	Envir. Taxes	Ener Tax	EPS
Explanatory variables:				
ES reporter*EI (Non-OECD partner)	0.026***	-0.021	-0.181***	0.153***
	(0.003)	(0.036)	(0.035)	(0.043)
ES reporter*EI (OECD partner)	0.031***	-0.113***	0.005	0.140***
	(0.004)	(0.029)	(0.003)	(0.035)
ES partner*EI (Non-OECD partner)	-0.016***	-0.040	-0.105***	-0.875***
	(0.005)	(0.041)	(0.018)	(0.053)
ES partner*EI (OECD partner)	-0.134***	-0.111***	-0.012*	-0.156***
	(0.038)	(0.023)	(0.007)	(0.045)
Observations	496,851	293,312	307,283	288,278
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

Looking at the environmental policy stringency in partner countries, we observe consistently negative coefficients, as expected, for all regulations, meaning that increasing environmental policy stringency in the exporter decreases imports from both groups of countries in industries with above average EI. The negative coefficients are of higher magnitude for OECD partners in two cases, for carbon price and environmental taxes (-0.134 versus -0.016 in column 1; -0.11 versus 0.04 in column 2). Nevertheless, in columns (2) and (3) we observe a non-significant coefficient for the stringency variable when imports come from non-OECD countries and a weakly significant coefficient when imports come from OECD. Finally, in column (4) the results show a significantly higher effect of environmental stringency (EPS in partner countries) on imports from non-OECD exporters than from OECD (-0.875 versus -0.156).

Next, we go a step further and estimate the results by distinguishing between polluting and neutral industries. The results are shown in tables 4 and 5, respectively. In these estimations we interact average energy intensity with the environmental stringency as we did before, and the obtained results for polluting sectors in Table 4 are in line with the main findings. We observe a positive coefficient for environmental stringency in the importer country for carbon pricing policies and for the EPS, in accordance with the theory indicating that more stringent environmental policies increase imports of polluting goods. Moreover, in this case the coefficient is higher than in the results for all goods (in Table 2), leading to the conclusion that the effect for polluting sectors is higher.

Table 4. Effects for Polluting Sectors. 2007-2018

Dependent variable: Imports	Carbon Price	Envir. Taxes	Tax Energy	EPS
Explanatory variable:				
ES reporter*EI	0.081***	-0.077***	-0.001	0.250***
	(0.020)	(0.027)	(0.010)	(0.020)
ES partner*EI	-0.199***	-0.081***	-0.021	-0.308***
	(0.040)	(0.021)	(0.017)	(0.028)
Observations	224,477	132,461	137,998	132,687
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

The results shown in Table 5 are mixed. The signs of the estimated coefficients are reversed for environmental taxes, when compared with those in Tables 2 and 3. This may suggest that trade of less polluting industries increases as environmental taxes become more stringent in both the importer and in the exporter countries. This could result from a composition effect, where OECD countries shift the composition of their exports towards less-polluting goods.

Table 5. Effects for Neutral Sectors. 2007-2018

Dependent variable: Imports	Carbon Price	Envir. Taxes	Tax Energy	EPS
Explanatory variables				
ES reporter*EI	0.849***	0.614***	-0.371*	0.874***
	(0.287)	(0.211)	(0.193)	(0.258)
ES partner*EI	-2.183***	0.443***	0.179	-2.000***
	(0.289)	(0.077)	(0.210)	(0.193)
Observations	272,350	160,844	169,284	155,591
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

In addition, in an attempt to fill in a highlighted research gap in the literature, we obtain similar results when we consider the heterogeneous effects among trading partners, as we observe higher coefficients in the trade relations with polluting products and non-OECD countries, which is in line with the expectations from the PHH (for more details please see Table A.4 in Appendix). For the neutral sectors there is considerable heterogeneity, but, overall, the results show that imports increase with the environmental stringency of the importer and decrease with environmental stringency in the exporter.

5.2. Robustness analysis

In this section we present additional results to check the robustness of our previous findings. First, in Table 6, we show results where the dependent variable is exports of goods as reported by the exporters (partner countries). As expected, the estimated coefficients obtained in these regressions confirm the main findings. The results are intuitive leading to the conclusion that an increase in environmental stringency in the exporter (reporter) country would lead to a decrease in exports, as production costs increase given the added burden of compliance. The decline in exports, related to an increase of 10 percent in environmental stringency, range from 4.02 percent, up to 10.6 percent. In the long run this can also lead to competitiveness issues for the most pollution intensive sectors, as mentioned above. We observe a positive coefficient for environmental policy stringency in the importer (partner) country in columns (1) and (2), which is interpreted as higher exports towards destinations with a carbon pricing policy or with higher environmental taxes.

Table 6. Results for exports. 2007-2018

Dependent variable: Exports	Carbon Price	Envir. Taxes	Tax Energy	EPS
Explanatory variables:				
ES reporter*EI	-1.057***	-0.483***	-0.402***	-0.646***
	(0.092)	(0.091)	(0.087)	(0.068)
ES partner*EI	0.163**	0.091***	0.034	-0.003
	(0.067)	(0.027)	(0.045)	(0.055)
Observations	1,031,769	304,808	435,557	291,021
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

We also performed additional specifications. First, we re-estimated the models excluding the agricultural sector and performed the analyses without centering the emissions intensity variable, when computing the interaction terms. As can be observed in Tables 7 and 8 below, our results confirm the robustness of our main findings leading to the same conclusion that more stringent environmental policies increase imports when considering carbon pricing policies or the environmental stringency policy index.

Table 7. Results for imports excluding the agricultural sector. 2007-2018

Dependent variable: Imports	Carbon Price	Envir. Taxes	Tax Energy	EPS
Explanatory variables:				
ES reporter*EI	0.027***	-0.052**	0.002	0.255***
	(0.003)	(0.020)	(0.005)	(0.028)
ES partner*EI	-0.118***	-0.060***	-0.013*	-0.349***
	(0.035)	(0.017)	(0.007)	(0.035)
Observations	474,684	275,655	289,819	272,709
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

Table 8. Results for imports without centering EI. 2007-2018

Dependent variable: Imports	Carbon Price	Envir. Taxes	Tax Energy	EPS
Explanatory variables:				
ES reporter*EI	0.027***	0.096***	0.002	0.230***
	(0.003)	(0.025)	(0.005)	(0.028)
ES partner*EI	-0.114***	-0.098***	-0.012**	-0.319***
	(0.034)	(0.020)	(0.007)	(0.033)
Observations	496,851	132,461	137,998	132,687
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

Finally, we have estimated models for each dirty sector, which allow us to evaluate the direct effect of the environmental variables on imports and to isolate the technique and scale effects, since the composition effect is only present at the aggregated level (Table 9). This contributes to fill one of the gaps in the literature and is in line with expectations and findings in Copeland, Shapiro, and Taylor (2022) and Levinson (2023). Moreover, we go a step deeper and account for the country's heterogeneity in our analysis, by performing further checks that consider the differential effects by OECD and non-OECD trading partners. Our results confirm the main findings from above by observing higher coefficients in the trade relations with polluting products and non-OECD countries (results are presented in Tables A.4 and A.5 in the Appendix).

The coefficients from Table 9 indicate that for some sectors more stringent regulations in the partner countries also increase imports. This is the case for six out of nine dirty sectors, including Wood, Paper, Coke; Chemical; Pharmaceutical; and Rubber, when countries have a carbon price, as shown in the first part of the table. The results are mixed for environmental (energy) taxes (second and third part of the table) with only three (two) sectors, Paper and Coke (Paper, Coke and Rubber) showing the expected increase in imports. The last part of the table presents a more consistent pattern for the EPS, which has market-based and non-market based environmental regulations, with positive coefficients for six out of nine sectors.

Table 9. Results for imports per each dirty sector

VARIABLES	(1) Mining	(2) Wood	(3) Paper	(4) Coke	(5) Chemicals	(6) Pharma	(7) Rubber	(8) Non-metal	(9) Basic Metal
Carbon Price reporter	0.008	0.114***	0.142***	0.230***	0.046***	0.131***	0.077***	0.028	-0.020
	(0.084)	(0.028)	(0.019)	(0.056)	(0.018)	(0.032)	(0.019)	(0.029)	(0.057)
Carbon Price_partner	0.129	-0.102**	0.022	-0.068	0.068***	0.206***	-0.036	0.011	-0.058
	(0.083)	(0.049)	(0.033)	(0.069)	(0.019)	(0.071)	(0.035)	(0.047)	(0.041)
N Observations	37,592	25,147	26,492	17,792	28,382	23,825	28,323	26,691	25,477
log(Envir. Taxes_reporter)	0.055	-0.094**	0.045**	0.177***	-0.002	-0.177***	0.024	-0.083**	-0.076**
	(0.093)	(0.042)	(0.019)	(0.043)	(0.018)	(0.061)	(0.015)	(0.034)	(0.037)
log(Envir. Taxes_partner)	-0.168***	-0.122***	0.069***	-0.134***	0.033	-0.131***	0.044***	-0.043	-0.022
	(0.033)	(0.017)	(0.013)	(0.043)	(0.021)	(0.045)	(0.011)	(0.027)	(0.032)
N Observations	12,924	14,799	15,519	10,961	15,976	14,253	16,692	15,855	14,973
log(Ener Taxes_reporter)	0.005	-0.108	0.035**	0.147***	0.019	-0.182***	0.055***	-0.028	-0.038
	(0.124)	(0.068)	(0.017)	(0.054)	(0.021)	(0.047)	(0.012)	(0.043)	(0.038)
Log(Ener Taxes_partner)	-0.081	0.146***	0.034	-0.203***	-0.029	-0.117	0.048	0.030	-0.096***
	(0.057)	(0.045)	(0.028)	(0.063)	(0.037)	(0.102)	(0.047)	(0.026)	(0.035)
N Observations	13,493	15,334	16,207	11,549	17,010	14,962	17,068	16,200	15,398
Log(EPS_reporter)	-0.296***	0.210***	0.117***	-0.092	0.026	0.512***	0.167***	0.210***	0.373***
	(0.085)	(0.081)	(0.027)	(0.085)	(0.023)	(0.080)	(0.024)	(0.035)	(0.064)
Log(EPS_partner)	-0.221***	0.074*	0.270***	0.007	0.205***	0.168***	0.246***	0.177***	-0.080**
	(0.034)	(0.038)	(0.019)	(0.064)	(0.022)	(0.063)	(0.013)	(0.024)	(0.035)
N Observations	13,409	14,889	15,445	12,227	15,690	14,645	15,684	15,285	15,280

Note: All models include reporter-partner and time FE. Robust standard errors, clusters at the pair level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6. CONCLUSIONS

Global environmental pollution and climate change have the potential to limit sustainable development paths in the world economy. Thus, an effective control of environmental pollution is essential to curb climate change, which is one of the most urgent issues faced by countries nowadays. In response, over the past decades governments around the world have actively implemented environmental regulations. Going forward, with the concept of green development, environmental regulations are likely to be continuously improved and play an increasing role in solving the externalities of environmental pollution and correcting market failures. Thus, an increasing number of countries have incorporated environmental factors into an important part of national and international regulation. At the same time, international trade has become an increasingly critical driver of economic development, and both developed and developing countries consider trade and investment as central part of their development strategies. In todays' world of growing economic activity induced by international trade, it is argued that environmental degradation will be accelerated unless it is protected by taking the necessary measures both at domestic and international borders.

This paper contributes to the growing body of literature on climate change and environmental discussions by examining whether stringent environmental regulations affect trade patterns, potentially creating competitive advantages for countries with less stringent regulations. In an attempt to fill some gaps in the related literature, we investigated whether the relationship between environmental stringency and trade varies across industries, based on their pollution intensity (dirty vs. neutral), and across the development status of their trading partners, using disaggregated trade data for a large sample of countries and incorporating various measures of environmental stringency, in order to deal with the multidimensionality issues in measuring environmental stringency. We do this by employing the latest panel-data econometric techniques for gravity models. A PPML estimator with high dimensional fixed effects is estimated for bilateral exports and imports using sectoral trade data.

Our main empirical results confirm that pollution controls tend to hinder export performance of firms and increase imports from countries with less policy stringent settings. This is specially the case for countries with carbon pricing policies and for those that have a combination of market and non-market based environmental policies in place. Moreover, we observe that these effects are more pronounced for pollution-intensive industries. Thus, we provide some evidence for the pollution haven hypothesis.

In terms of policy implications, we believe that our findings are very relevant and can inform the ongoing debates regarding the nexus and effects of environmental policies and international trade. This is even more relevant considering the current tendencies to renegotiate or dismantle (Brexit) trade agreements and rising protectionist pressures, or the upcoming roll-out of the European Union's Carbon Border Adjustment Mechanism (CBAM) expected to begin collecting payments in 2026.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support received from the Spanish Ministry of Science and Innovation and the EU (PID2023-147397NB-I00, FEDER 2021-2027), the Generalitat Valenciana (CIPROM50), as well as the University Jaume I (Project No. 23I468). We also thank the participants at the conferences held in Skopje, North Macedonia (EBTSF) in November 2024, Carcavelos, Portugal (AERNA) in September 2024, Valencia, Spain (INFER / INTECO) in September 2023, for the useful comments and suggestions received.

REFFERENCES

Andre, P., Boneva, T., Chopra, F., & Falk, A. (2024). Globally representative evidence on the actual and perceived support for climate action. *Nature Climate Change*, 14(3), 253-259.

Anderson, J. E. (1979). A theoretical foundation for the gravity equation. *American Economic Review*, 69, 106–116.

Anderson, J. E., and Van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *American Economic Review*, 93, 170–192.

Antweiler, W., Copeland, B. R., and Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review*, 91(4), 877–908.

Baghdadi, L., Martinez-Zarzoso, I., and Zitouna, H. (2013). Are RTA agreements with environmental provisions reducing emissions? *Journal of International Economics*, 90(2), 378-390.

Baier, S. L., & Bergstrand, J. H. (2007). Do free trade agreements actually increase members' international trade? *Journal of international Economics*, 71(1), 72-95.

Balsalobre-Lorente, D., Gokmenoglu, K. K., Taspinar, N., and Cantos-Cantos, J. M. (2019). An approach to the pollution haven and pollution halo hypotheses in MINT countries. *Environmental Science and Pollution Research*, *26*, 23010-23026.

Barros, L., and Martínez-Zarzoso, I. (2022). Systematic literature review on trade liberalization and sustainable development. *Sustainable Production and Consumption*, *33*, 921-931.

Bauckloh, M. T., Beyer, V., and Klein, C. (2022). *Does it pay to invest in dirty industries? New insights on the shunned-stock hypothesis* (No. 22-07). CFR Working Paper.

Bergstrand, J. H. (1985). The gravity equation in international trade: Some microeconomic foundations and empirical evidence. *The Review of Economics and Statistics*, 67, 474–481.

Balsalobre-Lorente, D., Gokmenoglu, K. K., Taspinar, N., & Cantos-Cantos, J. M. (2019). An approach to the pollution haven and pollution halo hypotheses in MINT countries. *Environmental Science and Pollution Research*, 26, 23010-23026.

Brunel, C., & Levinson, A. (2016). Measuring the stringency of environmental regulations. *Review of Environmental Economics and Policy*.

Brunnermeier S.B., Cohen M.A. (2003) Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economic Management* 45(2):278–293.

Carril-Caccia, F. and Milgram Baleix, J., (2024). "Impact of environmental regulation on MandAs in the manufacturing sector," *Journal of Environmental Economics and Management, Elsevier, vol. 127(C)*

Chakraborty, D., Mukherjee, S. (2013), How do trade and investment flows affect environmental sustainability? Evidence from panel data. *Environmental Development*, 6, 34-47.

Cherniwchan, J., B. Copeland, and M. S. Taylor (2017). Trade and the environment: New methods, measurement, and results. *Annual Reviews of Economics 9.*

Cole, M. A., and Elliott, R. J. (2003). Determining the trade–environment composition effect: the role of capital, labor and environmental regulations. *Journal of environmental economics and management*, *46*(3), 363-383.

Copeland, B.R. and S.M. Taylor (1994), North-South trade and the environment, *Quarterly Journal of Economics*, 109, pp. 755-787.

Copeland, B. R., and Taylor, M. S. (2004). Trade, growth and the environment. *Journal of Economic Literature*, 42(1), 7–71.

Copeland, Brian R., Joseph S. Shapiro, and M. Scott Taylor. (2022). “Globalization and the Environment.” In *Handbook of International Economics*, Vol. 5, edited by Gita Gopinath, Elhanan Helpman, and Kenneth Rogoff, 61–146. Amsterdam: North-Holland.

Correia, S., Guimarães, P., and Zylkin, T. (2020). Fast Poisson estimation with high-dimensional fixed effects. *The Stata Journal*, 20(1), 95-115.

Costantini V., Mazzanti M. (2012) On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports. *Resource Policy* 41(1):132–153.

Dechezlepetre, A. and M. Sato (2017). The Impacts of Environmental Regulations on Competitiveness. *Review of Environmental Economics and Policy* 11 (2), 183-206.

De Santis R., Esposito P., Lasinio C.J. (2021) Environmental regulation and productivity growth: main policy challenges. *International Econonomy* 165:264–277.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecological economics*, *49*(4), 431-455.

Duan, Y., Ji, T., Lu, Y., and Wang, S. (2021). Environmental regulations and international trade: A quantitative economic analysis of world pollution emissions. *Journal of Public Economics*, *203*, 104521.

Ederington, J., and Minier, J. (2003). Is environmental policy a secondary trade barrier? An empirical analysis. *Canadian Journal of Economics/Revue canadienne d'économique*, *36*(1), 137-154.

Ederington, J., Levinson, A., and Minier, J. (2005). Footloose and pollution-free. *Review of Economics and Statistics*, 87(1), 92–99.

Fabrizi A., Guarini G., Meliciani V. (2018) Green patents, regulatory policies and research network policies. *Resource Policy* 47(6):1018–1031.

Frankel, J. A., and Romer, D. (1999). Does Trade Cause Growth? *American Economic Review*, *89*(3), 379-399.

Gani, A. (2013), The effect of trade and institutions on pollution in the Arab countries. *Journal of International Trade Law and Policy*, 12(2), 154-168.

Grether, J. M., and De Melo, J. (2003). Globalization and dirty industries: Do pollution havens matter? (Vol. 9776). Cambridge, MA, USA: National Bureau of Economic Research.

Grossman, G. M., and Krueger, A. B. (1991). Environmental impacts of the North American free trade agreement (Working Paper 3914). Cambridge, MA: NBER.

Grossman, G. M., and Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, *110*(2), 353-377.

Irwin, D. A., and Terviö, M. (2002). Does trade raise income? Evidence from the twentieth century. *Journal of international Economics*, *58*(1), 1-18.

Irwin, D. A. (2024). Does trade reform promote economic growth? A review of recent evidence. *The World Bank Research Observer*, lkae003.

Jaffe, A. B., Peterson, S. R., Portney, P. R., and Stavins, R. N. (1995). Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us? *Journal of Economic literature*, *33*(1), 132-163.

Jakob, Michael. (2020). "Carbon Policy and International Trade" *Mimeo*

Kathuria, V. (2018). Does environmental governance matter for foreign direct investment? Testing the pollution haven hypothesis for Indian States. *Asian Development Review*, 35(1), 81-107.

Kearsley, A., and Riddel, M. (2010). A further inquiry into the pollution haven hypothesis and the environmental Kuznets curve. *Ecological Economics*, 69(4), 905-919.

Khalid, N., Aqeel, M., Noman, A., Khan, S. M., and Akhter, N. (2021). Interactions and effects of microplastics with heavy metals in aquatic and terrestrial environments. *Environmental Pollution*, 290, 118104.

Koźluk, T., and Timiliotis, C. (2016). Do environmental policies affect global value chains? A new perspective on the pollution haven hypothesis.

Levinson, A., Taylor, M.S. (2008), Unmasking the pollution haven effect. *International Economic Review*, 49(1), 223-254.

Levinson, A. (2023). Are developed countries outsourcing pollution? *Journal of Economic Perspectives*, 37(3), 87-110.

Lewer, J. J., and Berg, H. V. D. (2003). How large is international trade's effect on economic growth? *Journal of Economic Surveys*, *17*(3), 363-396.

López, L.A., Arce, G., Zafrilla, J.E. (2013), Parcelling virtual carbon in the pollution haven hypothesis. *Energy Economics*, 39, 177-186.

Mulatu, A. (2018). Environmental regulation and international competitiveness: a critical review. *International Journal of Global Environmental Issues*, *17*(1), 41-63.

Jaffe A.B., Peterson S.R., Portney P.R., Stavins R.N. (1995) Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us? *Journal Economic Literature* 33(1):132-163

Jaffe, A. B., and Palmer, K. (1997). Environmental regulation and innovation: a panel data study. *Review of economics and statistics*, *79*(4), 610-619.

Jin, J., Du, J., Long, X., Boamah, K.B., (2019). Positive mechanism of foreign direct investment enterprises on China's environment: Analysis of host country regulation and parent company management. *Journal of Clean Production*. 227, 207–217.

Martinez-Zarzoso, I., and Maruotti, A. (2013). The environmental Kuznets curve: functional form, time-varying heterogeneity and outliers in a panel setting. *Environmetrics*, *24*(7), 461-475.

Nie X., Wu J., Chen Z., Zhang A., Wang H. (2021) Can environmental regulation stimulate the regional Porter effect? Double test from quasi-experiment and dynamic panel data models. *Journal of Clean Production* 314:128027.

Paul, J., & Benito, G. R. (2018). A review of research on outward foreign direct investment from emerging countries, including China: what do we know, how do we know and where should we be heading? *Asia Pacific Business Review*, 24(1), 90-115.

Peiró-Palomino, J., Rodríguez-Crespo, E., and Suárez-Varela, M. (2022). Do countries with higher institutional quality transition to cleaner trade? *Ecological Economics*, *201*, 107554.

Poelhekke, S., Van der Ploeg, F., (2015). Green havens and pollution havens. *World Economy*. 38 (7), 1159–1178.

Porter, J. H., Parry, M. L., and Carter, T. R. (1991). The potential effects of climatic change on agricultural insect pests. *Agricultural and Forest Meteorology*, *57*(1-3), 221-240.

Porter, M. E., and van der Linde, C. (1995a). Toward a new conception of the environment competitiveness relationship. *Journal of Economic Perspectives*, 9(4), 97–118.

Rasit, N. B., and Aralas, S. B. (2017). *The Pollution Haven Hypothesis: An analysis of ASEAN and OECD countries*. (Proceedings of International Conference on Economics 2017), 96–109.

Rivera, J., Oh, C.H., (2013). Environmental regulations and multinational corporations' foreign market entry investments. *Policy Study Journal* 41 (2), 243–272.

Rocha, T. N., Martínez-Zarzoso, I., & Zaki, C. (2024). What Type of Trade is Promoted by Environmental Provisions in Trade Agreements? *Annals of Economics and Statistics*, (156), 207-236.

Rubashkina Y., Galeotti M., Verdolini E. (2015) Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors. *Energy Policy* 83:288–300.

Sawhney, A., & Rastogi, R. (2015). Is India specialising in polluting industries? Evidence from US-India bilateral trade. *The World Economy*, 38(2), 360-378.

Shao, Q., Wang, X., Zhou, Q., and Balogh, L. (2019). Pollution haven hypothesis revisited: a comparison of the BRICS and MINT countries based on VECM approach. *Journal of Cleaner Production*, 227, 724-738.

Silva, J. S., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and statistics*, 641-658.

Singh, T. (2010). Does international trade cause economic growth? A survey. *The World Economy*, *33*(11), 1517-1564.

Stern, D. I. (2017). The environmental Kuznets curve after 25 years. *Journal of Bioeconomics*, *19*, 7-28.

Tobey, J. A. (1990). The effects of domestic environmental policies on patterns of world trade: An empirical test. *Kyklos*, 43(2), 191–209.

Ulph, A. and L. Valentini (1998) "Is Environmental Dumping Greatet When Firms Are Footloose?" mimeo, University of Southampton.

Wang Y., Sun X., Guo X. (2019a) Environmental regulation and green productivity growth: Empirical evidence on the Porter Hypothesis from OECD industrial sectors. *Energy Policy* 132:611–619.

Wang H., Chen Z., Wu X., Nie X. (2019b) Can a carbon trading system promote the transformation of a low-carbon economy under the framework of the porter hypothesis? Empirical analysis based on the PSM-DID method. *Energy Policy* 129:930–938.

World Bank. 2023. State and Trends of Carbon Pricing 2023. http://hdl.handle.net/10986/39796 License: CC BY 3.0 IGO

Xu, X. (2000). International trade and environmental regulations: Time series evidence and cross section tests. *Environmental and Resource Economics*, 17(3), 233–257.

Yang X., Jiang P., Pan Y. (2020) Does China's carbon emission trading policy have an employment double dividend and a Porter effect? *Energy Policy* 142:111492

Zugravu-Soilita, N., 2017. How does foreign direct investment affect pollution? Toward a better understanding of the direct and conditional effects. *Environmental Resource Economy* 66, 293–338.

APPENDIX

Table A.1 Variables description and data sources

Variable	Description	Data source
Balanced International Merchandise Trade Statistics	Country pair dataset which has been balanced using the OECD methodology to reconcile the observed asymmetries in merchandise trade.	OECD https://www.oecd.org/en/data/datasets/oecd-balanced-trade-statistics.html
Carbon Price and Emissions Trading System	A dummy variable (1 if the country has a carbon tax or an ETS or both, and 0 otherwise)	World Bank – World Development indicators https://databank.worldbank.org/source/world-development-indicators
Environmental Taxes as % of GDP	Environmental taxes as a charge levied on a physical unit of an item that has a proven negative impact on the environment.	OECD https://www.oecd.org/en/data/indicators/environmental-tax.html
Taxes on Energy as % of GDP	All CO_2 -related taxes on energy products (e.g. fossil fuels and electricity) including those used in transportation	OECD https://www.oecd.org/en/data/indicators/environmental-tax.html
Environmental Policy Stringency Index	Country-specific and internationally comparable index of the stringency of environmental policy	OECD https://www.oecd.org/en/publications/measuring-environmental-policy-stringency-in-oecd-countries_90ab82e8-en.html
CO_2 emissions intensities	CO_2 emissions from fuel consumption by output	OECD https://data-explorer.oecd.org/?tm=GHGFPandsnb=5

Table A.2. List of sectors subdivided by polluting and neutral

Division ISIC Rev 4 - Neutral industries	Division ISIC Rev 4 - Polluting industries
1-3 Agriculture, forestry and fishing	5-9 Mining and quarrying
10-12 Food, bever. and tobacco	16 Wood and prod. of wood and cork
13-15 Textiles, leather and apparel	17-18 Paper and printing
25 Fabricated metal prod.	19 Coke and refined petrol.
26 Computer, electron. and optical prod.	20 Chemicals and chem. prod.
27 Electrical equipment	21 Pharmac., medicinal chem. Prod.
28 Machinery and equip.	22 Rubber and plastics
29 Motor vehicles	23 Non-metal. mineral prod.
30 Other transp. Equip.	24 Basic metals
31-33 Other manuf.	

Source: OECD Data and own elaboration. Note: Polluting industries are the ones that are above the overall CO2 intensity, why neutral are the ones below. Results are similar to Grether andMello (2003), Kozluk and Timiliotis (2016) and Bauckloh et al. (2022).

Table A.3. List of Countries

Reporter countries			
Australia	Austria	Belgium	Canada
Chile	Czechia	Denmark	Estonia
Finland	France	Germany	Greece
Hungary	Iceland	Ireland	Israel
Italy	Japan	Korea	Latvia
Lithuania	Luxembourg	Mexico	Netherlands
New Zealand	Norway	Poland	Portugal
Slovak Republic	Slovenia	Spain	Sweden
Switzerland	Türkiye	United Kingdom	United States

Note: OECD members in 2018.

Partner countries			
Afghanistan	Albania	Algeria	Angola
Antigua and Barbuda	Argentina	Armenia	Australia
Austria	Azerbaijan	Bahamas	Bahrain
Bangladesh	Barbados	Belarus	Belgium
Belize	Benin	Bermuda	Bolivia
Bosnia and Herz.	Botswana	Brazil	Brunei
Bulgaria	Burkina Faso	Burundi	Cabo Verde
Cambodia	Cameroon	Canada	Central African Rep.c
Chile	China (People's Republic of)	Chinese Taipei	Colombia
Congo	Costa Rica	Croatia	Cyprus
Czechia	Côte d'Ivoire	Denmark	Dominican Republic
Ecuador	Egypt	El Salvador	Estonia
Eswatini	Ethiopia	Fiji	Finland
France	Gambia	Georgia	Germany
Ghana	Greece	Greenland	Guatemala
Guyana	Honduras	Hong Kong	Hungary
Iceland	India	Indonesia	Iran
Iraq	Ireland	Israel	Italy
Jamaica	Japan	Jordan	Kazakhstan
Kenya	Kiribati	Korea	Kuwait
Kyrgyzstan	Lao People's D.R.	Latvia	Lebanon
Lesotho	Lithuania	Luxembourg	Macau, China
Madagascar	Malawi	Malaysia	Maldives
Mali	Malta	Mauritania	Mauritius
Mexico	Moldova	Mongolia	Montenegro
Morocco	Mozambique	Myanmar	Namibia
Nepal	Netherlands	N. Caledonia	New Zealand
Nicaragua	Niger	Nigeria	North Macedonia
Norway	Oman	Pakistan	Palau
Palestinian Authority	Panama	Paraguay	Peru
Philippines	Poland	Portugal	Qatar
Romania	Russia	Rwanda	Saint Kitts and Nevis
Saint Lucia	Saint Vincent and the Grenadines	Samoa	Sao Tome and Principe
Saudi Arabia	Senegal	Singapore	Slovak Republic
Slovenia	Solomon Islands	South Africa	Spain
Sri Lanka	Suriname	Sweden	Switzerland
Tanzania	Thailand	Togo	Tonga
Trinidad and Tobago	Tunisia	Türkiye	Uganda
Ukraine	United Arab Emirates	UK	United States
Uruguay	Venezuela	Viet Nam	Yemen
Zambia	Zimbabwe		

Table A.4. Heterogenous effects for polluting sectors and OECD partners

Dependent variable: Imports	Carbon Price	Envir. Taxes	Tax Energy	EPS
Explanatory variable:				
ES reporter*EI (Non-OECD partner)	0.066***	-0.005	-0.068	0.182***
	(0.020)	(0.013)	(0.094)	(0.016)
ES reporter*EI (OECD partner)	0.146***	-0.095***	0.003	0.182***
	(0.030)	(0.032)	(0.003)	(0.037)
ES partner*EI (Non-OECD partner)	-0.031**	-0.078	-0.083***	-0.734***
	(0.013)	(0.053)	(0.019)	(0.038)
ES partner*EI (OECD partner)	-0.289***	-0.095***	-0.011	-0.210***
	(0.046)	(0.025)	(0.008)	(0.049)
Observations	224,477	132,461	137,998	132,687
Reporter-partner FE	YES	YES	YES	YES
Reporter-time FE	YES	YES	YES	YES
Partner-time FE	YES	YES	YES	YES
Sector-time FE	YES	YES	YES	YES

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

Table A.5. Results for imports by dirty sectors and heterogenous countries - Carbon Price

VARIABLES	Mining	Wood	Paper	Coke	Chemical	Pharma	Rubber	Non metal	Basic Metal
Carbon price_reporter (Non-OECD partner)	0.197***	0.188***	0.318***	-0.056	0.209***	0.317***	0.201***	0.123***	-0.082*
	(0.056)	(0.041)	(0.040)	(0.063)	(0.037)	(0.056)	(0.026)	(0.034)	(0.043)
Carbon price_reporter (OECD partner)	0.452***	0.046	0.065***	0.385***	-0.027	0.107***	-0.006	-0.075*	0.022
	(0.068)	(0.030)	(0.019)	(0.071)	(0.018)	(0.035)	(0.025)	(0.042)	(0.092)
Carbon price_partner (Non-OECD partner)	0.171***	0.260***	0.069	-0.214**	-0.227***	0.537***	0.042	0.183***	-0.266***
	(0.062)	(0.039)	(0.083)	(0.086)	(0.077)	(0.106)	(0.082)	(0.061)	(0.053)
Carbon price_partner (OECD partner)	-0.177***	-0.208***	0.033	-0.103	0.099***	0.196***	-0.021	0.021	-0.032
	(0.058)	(0.058)	(0.034)	(0.077)	(0.018)	(0.073)	(0.034)	(0.045)	(0.049)
Observations	21,589	25,147	26,492	17,792	28,382	23,825	28,323	26,691	25,477
Reporter-partner FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

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