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Relationship Between CO_2 Emissions and Trade: The Case of the EU

Understanding the relationship between international trade and CO_2 emissions is crucial for designing appropriate measures to address climate change. This article focuses on CO_2 emissions as one of the trade flow determinants of the EU countries, along with other factors including remoteness, labour productivity, real effective exchange rates, and research and development expenditures. The authors conclude that EU exports and imports are growing to or from those partner countries whose CO_2 emissions are rising. Furthermore, the growing similarity between the emissions of the EU and partner countries supports mainly the growth of EU exports and points to the slowdown in the growth of partners' emissions intensity. The existence of a relationship between CO_2 emissions and EU trade is important for the expected effects of the Carbon Border Adjustment Mechanism to materialise. Thus, this study confirms the assumption that emissions can be reduced in EU partner countries through trade and trade measures.

Due to intensifying negative effects of the climate crisis, the relationship between international trade and CO_2 emissions gained attention not only in academia but also among policymakers. Understanding this relationship is important in designing appropriate measures for addressing climate change.

The effect of trade on CO_2 emissions seems ambiguous. On the one hand, trade allows for lower-emission goods, services and technologies to be distributed worldwide, which leads to lowering global emissions. An additional positive effect of trade on global CO_2 emissions is the pressure that trade openness puts on firms to increase their efficiency, including energy efficiency. On the other hand, however, trade contributes to the growth of CO_2 emissions through the environmental costs of transportation, mainly shipping. It also allows the production of emission-intensive goods to be moved from countries with high environmental standards to countries with lower CO_2 emission costs for producers. This, in turn, leads to higher global CO_2 emissions compared to situations without production shifting and subsequent trade, i.e. import of products to countries pursuing climate protection policies. This phenomenon is referred to as carbon leakage.

For countries pursuing CO_2 emission reduction policies, the implications of their policies on trade are particularly important. As Sato and Burke (2021, 1) explain:

> Attempts by governments to extract revenue from industry sectors with climate policies invariably will be met by opposition. Yet when faced by claims that climate policy will drive away jobs at the expense of domestic workers while having little impact on emissions anyway, policymakers and politicians must be able to explain the underlying causes.

The EU is considered to be the global leader in environmental and climate issues (Wurzel and Connelly, 2011). To prevent emission reduction measures in the EU from being accompanied by carbon leakage and an increase in the import of emissions-intensive goods, the EU has

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launched the Carbon Border Adjustment Mechanism (CBAM), as of 1 October 2023. During the transition period, which will run until the end of 2025, importers of several emissions-intensive goods will be required to report direct and indirect greenhouse gas (GHG) emissions contained in their imports without any payments. The new mechanism has initiated a great deal research focusing on its expected effects.

This article focuses on CO_2 emissions as one of the factors influencing trade flows of the EU countries along with other factors including remoteness, labour productivity, real effective exchange rates (REER), and research and development (R&D) expenditures as a share of GDP. Verification of the relationship between CO_2 emissions and EU trade is significant with regard to the adoption of CBAM.

Literature review

Several authors have empirically studied the relationship between international trade and CO_2 emissions. For EU countries, Shpak et al. (2022) investigated the dependence of CO_2 emissions on macroeconomic indicators including exports and imports between 1990 and 2020. They concluded that with increases in EU exports, its CO_2 emissions decreased while with increases in EU imports, CO_2 emissions increased.

The relationship between the rise of exports and the decrease in CO_2 emissions can be explained by the Porter hypothesis, according to which policy measures aimed at reducing CO_2 emissions stimulate innovation, productivity and reorientation towards fossil energy-sparing technologies and products (Porter, 1991). Porter's hypothesis has been verified by several empirical studies. Based on the evidence from firm-level data for Germany, Richter and Schiersch (2017) found a negative relationship between the export intensity of a company and its emission intensity indicating that exporting firms are less CO_2 emission-intensive than non-exporting ones. The same relationship was identified by Barrows and Ollivier (2021) in the case of manufacturing firms in India. Although the export growth led to growth in CO_2 emissions of these firms due to the output growth, it had a negative impact on CO_2 intensity growth.

As far as the relationship between import and CO_2 emissions increases is concerned, Fanelli and Ortis (2020, 141), in contrast to Shpak et al. (2022), argue that "replacement of European products with emerging countries' imports has led to an apparent decrease in EU's emissions". This was also found by Valodka et al. (2020), who investigated the impact of international trade on the EU clothing industry's carbon emissions. According to their results, along with production outsourcing, the EU has also outsourced CO_2 emissions. Ding et al. (2018) confirmed that China, as one of the major destinations for outsourcing, produced a high level of CO_2 emissions in the form of exports to other countries. From 2000 to 2014, CO_2 emissions embodied in Chinese exports to 38 countries including all EU countries increased significantly. After 2011, however, the CO_2 emission export intensity declined and was expected to decrease further. Similarly, Hu and Xu (2022) revealed that from 2002 to 2017, the expansion of the export trade scale improved the energy environmental efficiency and thus the CO_2 emissions efficiency in China. Han et al. (2022, 1253) explain that it is the upgrade of the industrial structure that plays a "significant mediating role in the export composition improvement for carbon reduction".

In order to reduce emissions and implement climate action, the EU has acted against carbon leakage by imposing CBAM on selected commodities with the highest emissions such as electricity, cement, aluminium, fertilisers, iron and steel products. It is also considering adding more types of plastic. Importing these commodities into the EU creates a new obligation to report the total quantity of goods imported in the period under review, including the amount of emissions tied to the production of the goods, together with the price already paid by the producer for carbon emissions in the country of production. In the future, a fee will by imposed on imports from areas with lower emission prices. The fee amount will be based on emissions from the production of the goods concerned (Overland and Huda, 2022). The idea that a carbon tax could become an effective tool in competition or a means of generating additional revenue for the importing country at the expense of the exporting country had to rise to the level of political decision-making sooner or later since companies producing emissions-intensive products such as steel and aluminium would have no incentive to introduce low-carbon production because of strong competitive pressures (Roginko, 2022). According to Lim et al. (2021), low-carbon industries will develop in the EU, which is expected to reduce import demand in the EU energy sectors.

Among the sectors subject to CBAM tariffs are the products that the EU imports the most: steel and aluminium. Overland and Sabyrbekov (2022) used open coding in the Atlast.ti machine learning programme to perform quantitative analysis of the content published by five EU aluminium companies in their financial reports and created a composite index. The analysis concluded that the countries' response to the CBAM will depend on their innovation capacity to cope with higher GHG costs. Clora and Yu (2022) underline the need to coordinate measures to decarbonise demand and supply across sectors in order to achieve ambitious emission reductions in Europe. Given the likely divergent changes in Europe's external trade between sectors and trading partners, appropriate domestic policies should be put in place to facilitate these changes. Authors of the study also point to a positive link between the progressive reduction of European GHG emissions and increasing carbon leakage, as well as between a worsening trade balance and increasing carbon leakage, which requires the EU, the UK and Switzerland to engage the rest of the world in global decarbonisation efforts.

The CBAM is likely to change the price dynamics of some countries, reduce incentives for firms to outsource their carbon emissions and support a more general transition to a low-carbon economy. Fairness concerns could be addressed by recovering revenues from carbon import adjustments and using them for technology transfer and international climate finance (Magacho et al., 2022). Zachmann and McWilliams (2020) argue that a carbon tariff should not be a fundamental element of the European Commission's climate policy. They claim that there is no evidence that the increase in the carbon price leads to the displacement of emissions-intensive production. The authors draw attention to the fact that introducing a carbon duty may reduce steel imports from countries with lower environmental requirements into the EU, and at the same time it may support imports of products that are made of steel. This may lead to so-called cascading protectionism, i.e. customs duties being extended to other products in the value chain (Jenčová, 2020).

Methodology

The aim of this study is to examine CO_2 emissions as one of the determinants of exports and imports of EU27 member countries using the Poisson pseudo-maximum likelihood gravity modelling with fixed effects (Anderson, 1979; Silva and Tenreyro, 2006; Bubáková, 2013; Fally, 2015). Models were primarily estimated in RStudio (R Core Team, 2022) with the Gravity 1.0 package (Wölwer et al., 2018; Wölwer et al., 2022) and with the econometric software GRETL (Adkins et al., 2015; Cottrell and Lucchetti, 2021). The estimators were verified using robust standard errors (Zeileis et al., 2020; Zeileis and Hothorn, 2002; Zeileis, 2004, 2021). Multilateral resistance terms were covered, adding fixed effects to our specifications (Adam and Cobham, 2007; Cheong et al., 2014; Hsiao, 2014; Yotov et al., 2016; König, 2021). For simpler calculations, fixed effects were added manually and only for exporters and importers, but the latest literature recommends using exporter-time, importer-time and exporter-importer fixed effects (Breinlich et al., 2021). We recommend this for further research.

We expanded our specifications of gravity models with an alternative approach of similarity between countries, inspired by Linder's (1961) work. The similarity between pairs of countries is measured by the similarity term, which is calculated as the absolute value of the difference between the decadical logarithms of the investigated variable of two partner countries (literature uses natural logarithms; Jošić and Basic, 2019; Kitenge, 2021). A negative coefficient estimation on the similarity term is interpreted as an increase in similarity.

Gravity modelling is based on the classic regression analysis of panel data with fixed ($\alpha_{i,j,s}$) and time effects (λ_t), where Y represents the dependent variable and X individual regressors (general regression equation; own processing by Lukáčiková, 2013; Lu and Su, 2020; ECB and Frohm, 2021; Fišera, 2022):

$$Y_{i,j,s,t} = \alpha_i + \alpha_j + \alpha_s + \lambda_t + \beta_1 X_{1_{i,j,s,t}} + \beta_2 X_{2_{i,j,s,t}} + \beta_{n-1} X_{n-1_{i,j,s,t}} + \beta_n X_{n_{i,j,s,t}} + u_{i,j,s,t}.$$

Table 1 presents the variables used in the study.

Table 1
Description of variables

Variable	Description
Export_EU_jst	Export of EU27 member states (i) to all available (not EU27) partner countries (j), divided down by 10 SITC product groups (s) from 2011 to 2019 (t). Missing values were replaced with zero (UNCTAD-Stat, 2022-2023).
Import_EU_jst	Import of EU27 member states (i) from all available (not EU27) partner countries (j), divided down by 10 SITC product groups (s) from 2011 to 2019 (t). Missing values were replaced with zero (UNCTAD-Stat, 2022-2023).
ln_Remot_jt	Natural logarithm of the partner country's (j) remoteness from the EU that was determined as the product of distance and the partners' share of global GDP (Mayer and Zignago, 2012; CEPII, 2011; WBG, 2022; LU Department of Econometrics, 2021). Because of fixed effects, remoteness should be interpreted as a change in the partner's share of global GDP over time.
Sim_GDP_ppe	Labour productivity as a share of GDP per employee in the form of similarity term (WBG, 2022).
Sim_REER	Real effective exchange rate as index in the form of similarity term (WBG, 2023). REER captures changes in exchange rates and price levels of partners (e.g. Pavelka et al., 2021).
Sim_RandD	R&D expenditures as share of GDP in the form of a similarity term (WBG, 2022).
Sim_CO_2	Carbon-dioxide emissions in the form of a similarity term (WBG, 2022).
ln_CO_2_kt_jt	Natural logarithm of the partner country's (j) CO_2 emissions in kilotonnes (WBG, 2022).

Source: Authors.

Table 2
Results of gravity models

	Export_EU_jst				Import_EU_jst			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
const	20.49 ***	8.49 **	21.39 ***	16.29 ***	17.98 ***	12.93 **	19.15 ***	7.69 ***
ln_Remot_jt	-0.91 ***	-0.94 ***	-1.03 ***	-1.04 ***	-0.66 ***	-0.69 ***	-0.84 ***	-0.88 ***
Sim_GDP_ppe	-1.58 ***	-1.42 ***	-1.59 ***	-1.54 ***	-2.28 ***	-2.19 ***	-2.50 ***	-2.31 ***
Sim_REER	2.10 ***	2.05 ***			2.05 ***	2.06 ***		
Sim_RandD	-0.14	-0.20 **			-0.50 ***	-0.51 ***		
Sim_CO_2_kt	-0.27 ***		-0.22 ***		-0.10 *		-0.01	
ln_CO_2_kt_jt		0.76 ***		0.31 ***		0.32		0.76 ***
n (t 2011-2019)	66,480		341,550		66,480		341,550	
PPML	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects i	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects j	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Confidence levels: *** 99%; ** 95%; * 90%.

Source: Authors' estimation.

Results and discussion

Table 2 contains the results. Models 1 to 4 are specified with the variable export of 27 EU member states to all countries with available data for the years 2011 to 2019. Models 5 to 8 work with the values of imports of 27 EU member states coming from all partners. From the set of partner countries, the EU27 countries were omitted in all models.

The number of observations (n) was determined by the chosen specifications of the gravity models and the availability of individual variables in the source databases. The analysed time series and its length were influenced by the availability of data for CO_2 emissions.

The partner remoteness variable has an estimated coefficient with the same sign and similar values. We can confirm that with the growing remoteness of the partner, we expect a decrease in both EU27 exports and imports. However, it should be emphasised that due to the inclusion of fixed effects in the specifications of the equations, it is not possible to estimate variables that do not evolve over time. For this reason, we can only interpret the change in the share of the partner's GDP in the global GDP for the partner's remoteness variable. Hence, EU27 countries trade more intensively with partners whose share of global GDP is decreasing. The share of advanced economies in world GDP is declining in favour of emerging economies. Our results are consistent with the results of studies by Steinhauser and Boros (2022) and Kittová et al. (2022). Although these studies analyse only one EU country, namely the Slovak Republic, with its high trade openness, it represents a suitable benchmark among the EU27 countries.

In the case of the labour productivity variable in the form of a similarity term, all estimated parameters are negative. This means that due to the increasing similarity of labour productivity of partners, we can expect higher EU27 exports to partners, as well as EU27 imports from partners.

The REER parameter in the form of a similarity term was included only in models 1, 2, 5 and 6. The reason is that REER data were available only for some (mostly developed) partner countries and the inclusion of this parameter in the specification substantially reduces the number of observations. The results for the REER parameter are particularly interesting considering the import and export values. Thus, our models confirm the classic theoretical assumptions according to which the increasing difference in REER increases the value of exports and imports of EU27 to and from its partners. In the case of depreciation or devaluation of the currency of the exporting country against the currency of the partner, the price competitiveness of exports increases. Currency appreciation or revaluation against the partner's currency supports imports from the partner country. The negative effect of an overvalued currency on the trade balance was confirmed by Fišera and Horváth (2022). However, globalisation and global value chains reduce the influence of exchange rate fluctuations on the domestic economy. Moreover, countries that have given up control over their own currency affect price competitiveness mainly by setting the tax wedge or the price of labour, not by influencing exchange rates (Turner and Van´t Dack, 1993; Baranová, 2013; Albu et al., 2022).

Like the REER variable, R&D expenditures were used only in some model specifications. Results of models 2, 5 and 6 show that the value of EU27 imports and exports is growing with the increasing similarity in R&D expenditures of partners. The estimated parameter in the specification of model 1 is, however, statistically insignificant, and therefore we cannot confirm the impact of the variable on EU27 exports.

Finally, we evaluate two variables expressing CO_2 emissions, which from the point of view of this research are the most important in our specifications. The results presented in Table 2 for the ln_CO_2_kt_jt variable show that EU27 exports are increasing to those partner countries whose CO_2 emissions are increasing. We explain this by the growing export of high-tech and environmental goods[1] from EU countries triggered by the production and consumption demand of partner countries (see e.g. Huiling et al., 2022 or Kerle et al., 2021). The growing demand, i.e. the import of partner countries, results from the growth of their industrial production, which is reflected in the growth of CO_2 emissions. The detailed statistics derived from the BACI database (Gaulier and Zignago, 2010; CEPII, 2023) and calculated using the dplyr package of the RStudio environment (Wickham et al., 2023) supports this conclusion. It shows that bilateral trade flows of environmental goods (IMF, 2021) from the 27 EU members to third countries increased from approximately US $221 billion in 2017 to almost US $285 billion in 2021. This time series showed stagnation only between 2019 and 2020 due to the pandemic.

Furthermore, based on the estimated coefficient of the variable ln_CO_2_kt_jt in model 8, we can assume that EU27 imports from partner countries with growing CO_2 emissions are also increasing (in the period from 2011 to 2019 they included, for example, China, India, Vietnam, Malaysia and Thailand). We interpret this finding in line with Fanelli and Ortis (2020) or Valodka et al. (2020) as a consequence of the rising costs of CO_2 emissions in the EU, which lead to the reduction of CO_2-intensive production in the EU and its transfer to countries with lower costs of CO_2 emissions. Subsequently, the EU imports the CO_2-intensive production of these countries. This interpretation also tracks with the findings of studies on introducing CBAM in the EU (Lim et al., 2021; Clora and Yu, 2022), which point to the fact that Europe's GHG emission reductions are offset by increased emissions elsewhere, and production is dispersed in several countries because of the global value chains.

The negative coefficient estimation on the similarity term for CO_2 emissions expresses that with an increase in the similarity of CO_2 emissions between the EU and partner countries, EU27 exports to partner countries increase (models 1 and 3). The influence of the similarity of emissions on EU27 imports was confirmed only marginally in model 5. Based on the results, we reject the null hypothesis of insignificance of the estimate of this variable with 90% probability. The growing similarity of CO_2 emissions of the EU and partner countries (such as China and India) is explained by the so-called closing of the gap in the development of CO_2 emissions, i.e., slowing down the growth of these countries' emissions, which corresponds to the findings of Hu and Xu (2022) or Han et al. (2022).

It is important to note that there is no single so-called global methodology for calculating CO_2 that is comparable among all countries in the world. This gives companies a choice of several calculation methodologies (e.g. under the GHG Protocol), which implies that the comparability and reporting of CO_2 when importing certain commodities into the EU may be distorted. Based on evidence, we expect a rather negative attitude of other countries towards CBAM in the short term. CBAM is expected to reduce imports of the commodities concerned. This, in turn, may lead to cascading protectionism. In the longer term, however, we assume that introducing a carbon tariff in the EU will contribute to reducing global emissions by changing the composition of production within and between countries. However, this requires climate policy synergies of the world's strongest economies (EU, US, China) and help from developed countries to developing countries. Based on studies focused on CBAM in the EU and its impact on changing trade patterns, we can summarise several policy recommendations:

- coordinate measures aimed at decarbonising not only demand but also supply in all sectors in Europe, which requires the implementation of appropriate domestic policies;
- involve the rest of the world, mainly China and the US, in global decarbonisation efforts (Clora and Yu, 2022);
- assess which countries are most likely to become the biggest opponents of the CBAM (Overland and Sabyrbekov, 2022), mitigating the impact of CBAMs in these

1 Environmental goods include both goods connected to environmental protection like those related to pollution management and resource management, and goods that have been specifically modified to be more environmentally friendly (IMF, 2023).

countries and offering support for their decarbonisation, for example through technology transfers;

- use the CBAM revenues for financing climate protection and technology transfer (Magacho et al, 2022).

Conclusions

Our research confirmed the existence of a relationship between CO_2 emissions and EU27 trade. We conclude that EU exports and imports are growing to or from those partner countries whose CO_2 emissions are rising. We explain these results in the case of EU exports by the growth of demand from partners with increasing CO_2 emissions for high-tech and environmental goods. In the case of EU imports, this is a consequence of moving CO_2-intensive production from the EU to partner countries and importing it to the EU. The growing similarity between the emissions of the EU and partner countries mainly supports the growth of EU exports and points to the slowdown in the growth of partners' emissions intensity. However, in drawing these conclusions, it is important to point out the limitations of the research arising from the fact that the CO_2 emission indicator used does not reflect the determinants of emissions such as sectoral composition of the economy, transport, energy efficiency, etc. We therefore recommend that future research should take these determinants into account. Another limitation of our study results from the availability of individual variables in the source databases, the time series analysed and its length. Therefore, we recommend the verification of results presented in this study using data for the coming years.

The existence of a relationship between CO_2 emissions and EU trade is important for the expected effects of the CBAM to materialise. This mechanism is expected to support environmental goods production in the EU, decrease unit costs of such production, and increase its affordability and its wider use in other countries leading to growing EU exports of environmental goods. CBAM is also expected to limit CO_2-intensive imports to the EU and thus promote the introduction of climate policies aimed at reducing CO_2 emissions in partner countries. A significant limitation of this assumption can be seen in the mismatch of countries' CO_2 calculations. Therefore, the adoption of a single methodology for CO_2 measurement is recommended. Moreover, measures to mitigate climate change should be based on the adoption of a global carbon price for GHG emissions based on the place of production. It is also important to avoid cascading protectionism and use government revenues from the carbon tax to promote more efficient production – not only of raw materials but also of all links in the supply chain – with the common goal of reducing the carbon footprint. This requires a change in the composition of production in the coming years.

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