# The Impact of the EU Plastic Waste Export Ban on EU exports to OECD, relative to other trade flows

## A Gravity Model Analysis of Bilateral Trade Patterns (2017-2023)

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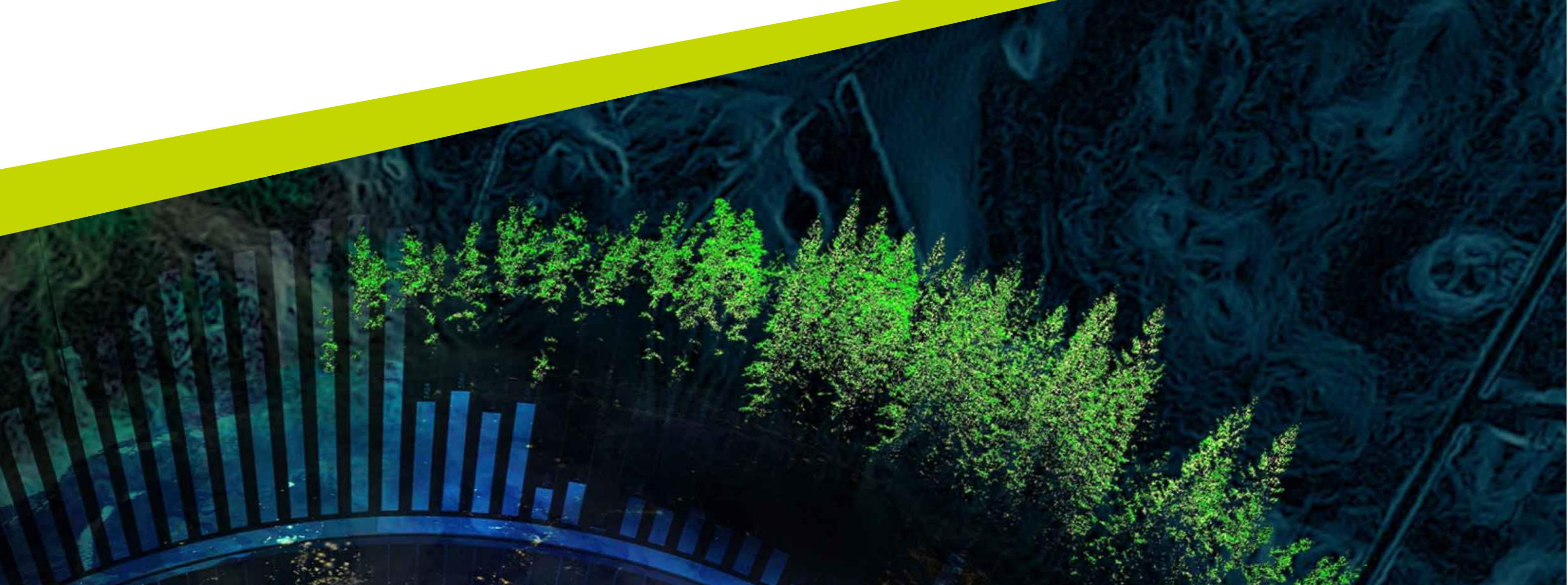

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## Abstract

This paper investigates the effects of the European Union's 2021 ban on plastic waste exports to non-OECD countries. Using bilateral trade data from 2017 to 2023, this study applies a Poisson-Psuedo Maximum Likelihood (PPML) estimator to with various sets of fixed effects to capture the causal effect of the ban. EU exporters, OECD importers, and the post-2021 period capture the regulation's differential impact. Results suggest a modest, statistically insignificant adjustment in EU exports to OECD countries relative to pre-2021 trade and non-EU exporters, indicating limited redirection of flows under the ban. Standard gravity variables, such as distance and GDP, exhibit expected effects, supporting model robustness. These findings provide nuanced evidence on the trade effects of environmental regulation, illustrating that while the EU ban may shift trade patterns toward OECD countries, the overall impact on bilateral flows is subtle. The study contributes to the literature on environmental trade policies and the evaluation of transboundary waste regulations, offering insights for both researchers and policymakers.

*Keywords: Plastic waste trade, Gravity model, Trade diversion,*

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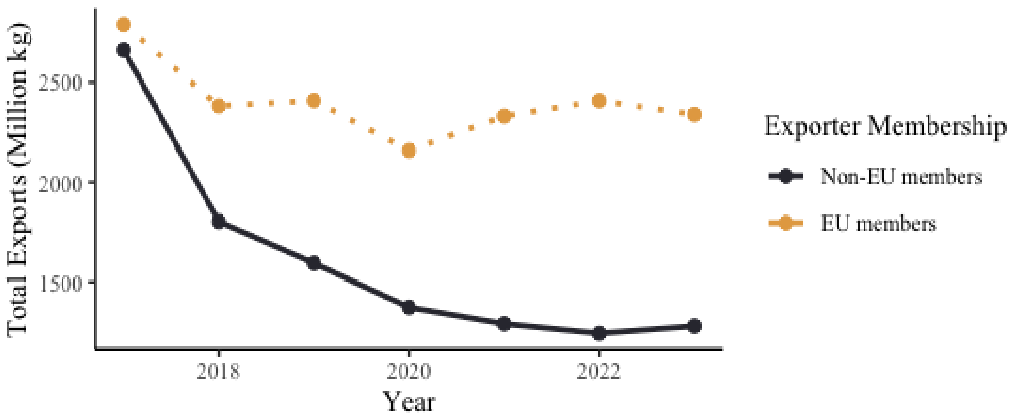
# Abbreviations

| Abbreviation | Description |
| --- | --- |
| EU | European Union |
| FE | Fixed Effect |
| MRT | Multilateral Resistance Term |
| OECD | The Organisation for Economic Co-operation and Development |
| OLS | Ordinary Least Squares |
| PPML | Poisson-Psuedo Maximum Likelihood |
| RTA | Regional Trade Agreement |

# 1. Introduction

Plastic pollution now pervades every ecosystem on Earth, and will persist for centuries, breaking into micro- and nanoplastics. Plastic pollution threatens both human and environmental health. Our global production of plastic has risen drastically from 2 million tons in 1950 to 367 million tons in 2020 (Jiang *et al.*, 2022), with approximately 50% of the produced plastic becoming waste after a single use. Despite various policy efforts aimed at mitigating the growth of disposal, projections suggest that by 2025, nearly 12 billion tons of plastic waste will accumulate in our environment and landfills. Developed economies, characterised by stricter regulations and higher disposal costs, account for a significant share of plastic waste exports. In contrast, developing economies with insufficient infrastructure and regulatory capacities account for a large share of waste imports. The European Union (EU) is one of the largest waste exporters and represented 16% of the total global plastic waste exports in 2020. Only 29.7% of their plastic waste was exported to OECD member states (Halleux, 2024). Figure 1 illustrates how EU countries export higher levels of plastic waste collectively compared to non-EU countries.

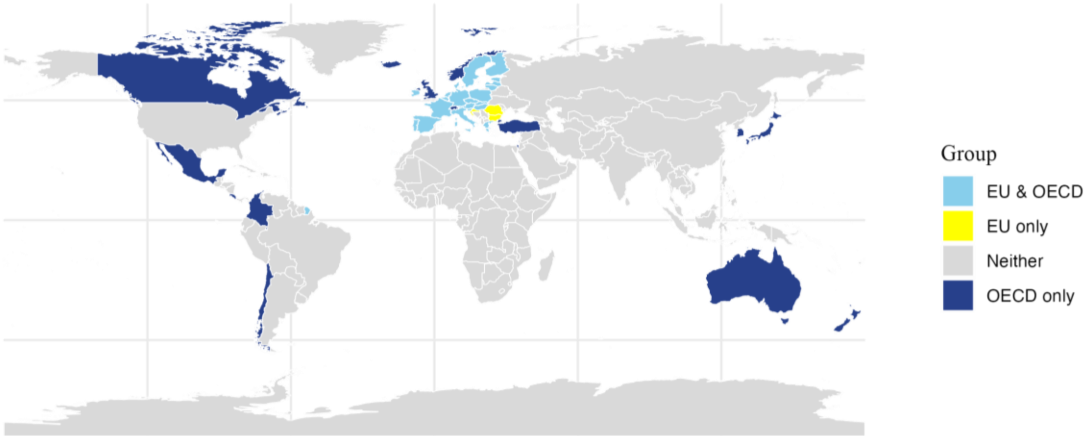
*Figure 1. Total Plastic Waste Exports by EU Membership*




*Note: Figure 1 shows total annual exports of plastic waste by EU exporter status, 2017-2023. The figure shows total export volumes in million kilograms from EU (pink-dotted line) and non-EU (black-solid line) exporters over time. Source: UN Comtrade (2025).*

These trade dynamics are often due to a combination of environmental risk aversion and economic incentives, and such trade patterns have become increasingly prevalent in the 21st century and act as the foundation of the Pollution Haven hypothesis. The Basel Convention Plastic Waste Amendments (BCPWA) represent a multilateral attempt to limit hazardous waste exports from developed countries to developing countries. To contextualise the EU's plastic waste trade patterns, Figure 2 displays a map of country groups based on EU and OECD memberships. Previously, 70.3% in volume of plastic waste exports from EU countries ended up in the non-OECD countries based on 2018/2019 average values.

*Figure 2. Country Groups based on EU and OECD Membership*




*Note: Figure 2 displayes a map of country groups based on their membership status in 2023. Countries that are member states of both EU and OECD are shown in blue, only EU member states are shown in yellow, only OECD member states are shown in navy and countries that are member states of neither EU nor OECD are shown in grey. Source: (EU countries | European Union, no date: OECD, 2025)* [1]

To mitigate the risk of improper waste management, in 2021, the EU introduced a ban on all plastic waste exports to countries that are not members of the Organisation for Economic Co-operation and Development (OECD). This regulation aims to prevent the externalisation of waste management responsibilities to non-OECD countries. The new regulation implies that from 1st of January 2021, EU member states are only permitted to export plastic waste to OECD member states. The 2021 EU plastic waste export ban marks a pivotal regulatory shift in global trade dynamics, presenting a unique opportunity for empirical investigation. How did the ban affect trade flows from EU to OECD countries, relative to other trade flows?

This study addresses this question by analysing how the EU plastic waste export ban has affected international plastic waste trade patterns to OECD countries, relative to other trade flows. The main objective of this study is to examine how EU exports of plastic waste changed after the implementation of the ban. To address

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[1] For reference, a full list of EU and OECD member countries included in this study is provided in Appendix 2. These classifications are used to construct the key policy variables and interaction terms in the analysis, ensuring that the effects of the 2021 EU plastic waste ban are consistently captured across all relevant countries.

these questions, the analysis uses panel data on the bilateral trade of plastic waste from 2017 to 2023. It builds on the gravity model of trade by employing a Poisson Pseudo-Maximum Likelihood (PPML) estimation. While modern research in the field often investigates trade dynamics using a PPML approach over Ordinary Least Squares (OLS), most existing literature examines trade flows in terms of regional trade agreements (RTAs) (Adarov, 2023; Carrère, 2006; Nguyen, 2019). This study aims to fill this gap in the literature by examining how EU trade flows changed after the export ban to non-OECD countries.

This study makes two key contributions. First, it offers timely empirical evidence on the effects of the EU's plastic waste export ban. By using a robust econometric regression model with fixed effects on real-world panel data, this study aims to build on the existing literature. Second, by analysing whether the ban caused redirection of harmful waste to other regions, this thesis contributes to the debate on the Pollution Haven Hypothesis.

# 2. Background

## 2.1 The Gravity Model of Trade

This study aims to analyse the effects of the EU's 2021 ban on plastic waste exports to non-OECD countries. The analysis is grounded in the gravity model of international trade, inspired by Isaac Newton's law of gravity. Often, the gravity model is widely used to study bilateral trade, this analysis focuses particularly on plastic waste flows. It is a partial equilibrium model, capturing the effects of the EU export ban within the plastic trade market rather than the second and third order impacts across other goods. The gravity model suggests that trade flows between two countries are positively dependent on their economic size and inversely on their trade costs. Typically, economic size is measured by Gross Domestic Product (GDP), and the distance between countries is often used as a proxy for trade costs. Walter Isard (1954) was likely the first to introduce this model in international economics, building on John Quincy Stewert's earlier concept of demographic gravitation. The foundational gravity model of trade between a pair of exporting country *i* and importing country *j*, with capturing unobserved factors, is formulated as follows:

$$Trade_{ij} = G \frac{GDP_i^{\alpha} GDP_j^{\beta}}{Distance_{ij}^{\gamma}} \varepsilon_{ij} \qquad \textit{(Equation 1)}$$

In equation 1, is a constant and is the bilateral trade flow from country $i$ to country $j$. $GDP_i$ and $GDP_j$ represent the economic size (mass) of the importing and exporting countries. $D_{ij}$ is the distance between them and an elasticity. The model shown in equation 1 has proven successful in expaining trade dynamics and will be used as the baseline framework in this thesis to analyse trade flow. The nature of this model suggests that larger economies trade more and that distance decreases trade. In this study, the gravity model of trade is adapted to examine the effects of the EU's ban on plastic waste exports. Furthermore, this study investigates explicitly if this policy changed trade patterns of plastic waste from EU countries to the rest of the world.

## 2.2 Trade Theory on plastic waste

The trade dynamics in plastic trade are fundamentally different from standard trade theories that assume heterogeneity in consumption goods. A PET bottle in Finland is equivalent to one in Sweden. Thereby, the trade dynamics of plastic waste are shaped more by economic, institutional and environmental factors rather than consumer preferences.

### 2.2.1 Ricardian perspective with comparative advantage

In the classic Ricardian model, comparative advantages stem from differences in relative productivity across goods. However, when the good is homogeneous across countries (disposal of plastic waste), the comparative advantage is less about production productivity and more about the relative cost and disutility of managing waste disposal. Thus, the productivity aspect in the Ricardian model can be reinterpreted as a country's efficiency in processing or recycling plastic waste. The good that is being traded, is hence, not plastic waste itself but rather the service of disposal. Improper disposal of plastic waste comes with serious environmental and health risks. Hence, every unit of plastic waste that is properly disposed of generates utility for society as the environmental and health risks are reduced. For instance, consider a simplified world with only two countries: Country A (a high-income EU member) and Country B (a low-income non-OECD member). Country A faces high financial and regulatory costs for proper waste disposal, while Country B can process waste cheaper due to lower labor costs and laxer environmental regulations. From a private perspective, Country A has an incentive to export waste since it reduces disposal costs. However, from a societal perspective, exporting to Country B may generate high environmental and social costs, which are not reflected in the financial transactions. Despite Country A's technical advantage, its high domestic treatment costs create a comparative disadvantage in processing waste. With its lower costs, Country B becomes a natural importer of the disposal when compensated financially by Country A. In the absence of regulation, trade will flow from Country A to B despite environmental risks, which is a direct consequence of private optimizing behavior.

From a social perspective, the comparative advantage in waste disposal differs from the private. While firms focus on minimizing their private costs, society bears the broader environmental costs of mismanaged waste. As Country B has lower private disposal costs, it may have a higher social cost, which creates a misalignment between private incentives and social welfare. In the context of the 2021 EU ban, the regulation can be interpreted as a policy measure that forces a shift in the trade of disposals to countries with higher social comparative advantages. Similarly to Country A, OECD membership works as a proxy for safe and efficient waste management, aligning private decisions with social welfare. Thus, each unit of properly disposed plastic generates societal utility, which the market alone may not internalize. This further highlights the role of regulations in maximizing net social benefits.

### 2.2.2 Link to the Pollution Haven Hypothesis

This dynamic is closely aligned with the Pollution Haven Hypothesis (PHH), which posits that firms in countries with strict environmental regulations will reallocate environmentally harmful production of goods to countries with laxer regulations. The PPH framework often refers to goods being either “dirty” or “clean”. The most common dirty industries produce goods mainly from iron and steel, industrial chemicals, non-metallic mineral products, pulp and paper and non-ferrous metals (Perman and Perman, 2011). They are considered dirty goods/industries because they are highly pollution-intensive in their levels of abatement expenditure per unit and output. Within this framework, trade is not of a pollution-intensive good from a dirty industry, but rather a negative externality, more specifically, an environmentally harmful disposal of plastic waste. Thus, plastic waste trade theory aligns with the logic behind the PHH since high-income countries effectively export negative externalities to low-income countries and reflects regulatory arbitrage where countries optimise across differing levels of environmental enforcement. In particular, the 2021 EU plastic waste export ban to non-OECD countries can be interpreted as a policy response to such arbitrage, which aims to prevent offshoring of environmental harm by restricting trade based on established waste capacities.

### 2.2.3 Hecksher-Ohlin perspective with Factor Endowments

The Heckscher-Ohlin model provides valuable insights when adapted to plastic waste trade. Countries export goods that use their abundant factors intensively. Applying this to plastic waste suggests that developed countries (EU and OECD members) dispose of plastic waste by using highly technical facilities that generate large social benefits but also high private costs for firms. Meanwhile, the waste disposal management in developing countries (non-OECD members), is often not as technically advanced. With abundant land and cheap labor, the developing countries have lower private costs of waste management. This over supply of waste to developing countries can produce negative social benefits. According to the Hecksher-Ohlin model, countries abundant in the factors used intensively in production specialize in the corresponding activity. In contrast, countries with scarce land and scarce low-skilled labor face higher private costs in waste processing, even if the social returns from reducing environmental damage are high. This theoretical framing captures structural inequality in trade flows: environmental costs are externalized from high-income, factor-scarce countries to low-income, factor-abundant countries. As a result, non-OECD countries tend to import more plastic waste and bear disproportionate environmental burdens. These dynamics could partially explain why the EU is one of the largest plastic waste exporters and why non-OECD countries are large waste importers. Plastic waste in this context is thus not only a commodity but also a vehicle for transferring environmental burdens across countries.

Aside from comparative advantages and factor endowments, political interventions also play a significant role in shaping waste trade dynamics. The EU's introduction of a legal barrier based on OECD membership is one example of a political intervention that alters the structure of plastic waste trade patterns. The ban acts as an exogenous shock, significantly changing the legality of specific trade flows, independent of their economic efficiency. This is a clear example of political action on waste trade and environmental welfare.

In this context, it is crucial to consider how institutional affiliations, relationships between institutions, affect trade flows through regulatory access or exclusion rather than price mechanisms. While traditional trade liberalization reduces barriers to increase trade abilities, this policy restricts access for a large group based on regulatory alignment. Given the nature of the policy, the possibility to trade is now binary - either permitted or prohibited. The empirical strategy of this study is grounded in the structure of the policy. Where continuous economic factors do not drive the outcome, but solely on institutional memberships. The theoretical framework is employed through the lens of multiple strands of trade theory.

## 2.3 Institutional context

The implementation of the EU's plastic waste trade regulation was discussed in the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their disposal in 2017. It came into force on January 1, 2021 (United Nations, 2019). Prior to the ban, a significant share of the EU's plastic waste was exported to non-OECD countries, many of which lacked adequate waste management capacities. The EU implemented the ban to improve global environmental standards and prevent illegal dumping of plastic waste.

The EU is a political and economic union that consists of 27 European countries that share common institutions, policies, and regulatory frameworks (see Appendix 2). The European Commission represents the common interests of the EU. It makes decisions on proposals for new laws that the European Parliament and the Council of the European Union later scrutinise and adopt. All regulations and decisions will automatically become binding throughout the EU once the legislation comes into force. Hence, the 2021 ban applies to all EU member states and goes beyond any domestic trade agreements within a country.

The OECD serves as a proxy for high environmental and institutional standards, which makes an OECD membership a credible indicator of a country's ability to handle waste sustainably. The organisation aims to set international standards through improved economic performance, fighting climate change, and encouraging education (OECD, 2021). Hence, by strictly restricting plastic waste exports to OECD members, the EU effectively redefines trade feasibility in binary terms: a partner is either eligible or not eligible. From a modelling perspective, the 2021 EU ban functions as an exogenous institutional shock by altering flows through shifting the trade rules. This setting creates an opportunity for quasi-experimental analysis.

# 3. Literature

This study is draws primarily from the literature on the effectiveness of international trade agreements within the environmental and trade literatures. The gravity model of trade has become a cornerstone in empirical analyses of bilateral trade patterns, and its empirical robustness and simplicity have led to the development and adaptation of the model in academic research and policy analyses. The core prediction of the gravity model of trade is that bilateral trade flows between two countries are positively related to their economic size and negatively related to the distance between them. The traditional prediction reflects the idea that larger economies and shorter distances promote more trade, which Tinbergen (1962) established as a practical and empirically successful approach to studying trade. While key trade gravity indicators were tested in this study, the traditional OLS approach was disfavored for PPML. The primary concern of OLS estimation in trade theory is, first, the challenges with zero trade flows, and secondly, the resulting heteroskedasticity. Observations with zero trade flows are common within bilateral trade analysis, particularly when a dataset is extensive and covers a more extended period, which is the case for the dataset used in this study as well. To address the issue with zero trade flows, this thesis applies a PPML estimator as recommended by Silva and Tenreyro (2006). The PPML estimator addresses some of the limitations when using an OLS estimator. Silva and Tenreyro (2006) showed that unlike the OLS estimator, PPML handles zero trade values without the risk of data loss as well as provides robust results despite the presence of heteroskedasticity. Their findings have significantly influenced later empirical trade research by suggesting a shift from OLS estimation to PPML in gravity models. Applying a PPML estimation is now the standard practice when estimating bilateral trade flows (Burger, Van Oort and Linders, 2009; Helpman, 2008; Martin and Pham, 2020; Melitz and Rubinstein, 2008).

In more recent trade literature after the 2000s, the inclusion of multilateral resistance terms has become a standard practice. Anderson and van Wincoop (2003) advanced the traditional gravity model by incorporating multilateral resistance terms, thereby providing a theoretical foundation for the gravity model. Introducing multilateral resistance terms shows that bilateral trade flows are affected by the country's relative access to trading partners, and not only trade costs (measured in distance). Although I don't estimate the structural resistance terms in the style of Anderson and van Wincoop (2003), I do follow the empirical gravity tradition and accound for fixed bilateral factors using an array of fixed effects. While PPML estimators address the issue with zero trade flows (Martin and Pham, 2020; Silva and Tenreyro, 2006), another significant challenge arises from unobserved heterogeneity between the trading countries. As including multilateral resistance terms is the traditional approach to capturing trade factors, Westerlund and

Wilhelmsson (2011) propose the use of panel data methods. Their insights on how fixed effects in panel data successfully capture a large part of the heterogeneity across countries over time, effectively control for unobserved factors such as multilateral resistance terms, lay the foundation for the model estimations of this study. The use of high-dimensional fixed effects allows the model to control for observed and unobserved heterogeneity, without necessarily relying exclusively on the standard gravity variables (Baier and Bergstrand, 2007; Feenstra and Kee, 2004; Westerlund and Wilhelmsson, 2011). The use of bilateral fixed effects is widespread, as it controls for a wide range of potential bilateral determinants while allowing time-varying determinants such as trade agreements to be identified (Adarov, 2023; Anderson, Larch and Yotov, 2018; Ishimura, Ichinose and Nomura, 2025; Nguyen, 2019). Country-pair fixed effects, however, come with a crucial limitation in the context of this study. Since the member states of the EU and OECD remain constant throughout the period (2017-2023), these key identifying variables are time-invariant and will thereby be absorbed by the country-pair fixed effects. While Ishimura, Ichinose and Nomura (2025) prove that the main effect could still be interpreted through interaction terms, country-pair fixed effects are not ideal in this study and will instead be used as robustness check (see Appendix 5).

As argued by Magee (2008), fixed effect panel estimation allow the model to analyse bilateral trade flows, without strictly relying on the traditional gravity variables. Building on this, Anderson, Larch and Yotov (2018) reinforce the methodological integrity of PPML in trade policy contexts by providing a complex framework for general equilibrium gravity estimation with PPML, including best practices for implementing fixed effects to absorb multilateral resistance terms. They particularly emphasize the importance of including high-dimensional fixed effects to control for unobserved heterogeneity in trade settings where a policy, such as the EU ban, causes an immediate shift in trade flows.

Adarov (2023) evaluates the impact of Eurasian economic integration on bilateral trade flows by using the PPML approach alongside the Synthetic Controls (SC) methods. Similarly to Silva and Tenreyro (2006), Adarov highlights PPML estimation in trade analysis due to its ability to address zero trade flows and heteroskedasticity. To test the robustness of his study, Adarov conducts several robustness checks, including a placebo test to assess whether the estimated effects are due to policy changes rather than broader time trends. His use of fixed effects for exporters, importers and years aligns closely with best practice outlines by Silva and Tenreyro (2006), which is also used as a guideline for the methodology in this study. They realized that when they used a three-way fixed effects estimation on grouped dummies, the estimation of those variables could not be directly examined. Instead, they examined the effect of the dummy variables through an interaction term and compared the robustness of their results with other approaches. Ishimura, Ichinose and Nomura (2025) used a Difference-in-Difference (DiD) design to examine the effects of international agreements on plastic waste trade. In addition to a DiD approach, they conducted a PPML estimator with three-way fixed effects. Similarly to Adarov (2023), they faced issues with multicollinearity between group dummies and fixed effects. The effect of ITAs on trade dynamics was instead captured through a triple interaction term, alongside several different approaches to check the robustness of the coefficient values. Their work further illustrates the regulatory mechanisms and substitution effects that may occur when high-income countries are restricted from exporting plastic waste to lower-income nations. Their findings also support the idea that policies can cause rerouting, rather than descrease trade flows. growing body of research examines the interaction between environmental regulations and international trade, particularly in the context of waste management.

Li and Takeuchi (2023) provide a closely related study, analyzing the effects of China's 2017 waste import ban on both trade flows and air pollution. Using a quasi-experimental design and econometric panel data methods akin to the PPML DiD approach, they find that regulatory restrictions can shift trade patterns and influence environmental outcomes, although the magnitude and direction of trade adjustments vary across regions. Conceptually, Kellenberg and Levinson (2014) explore the role of international environmental agreements in shaping pollution outcomes, illustrating how supranational regulations can create incentives or constraints that alter cross-country flows of environmentally sensitive goods. While their analysis is broader and does not focus exclusively on waste trade, the study reinforces the idea that regulatory shocks such as the 2021 EU plastic waste ban, can generate observable shifts in trade networks. Together with Ishimura, Ichinose and Nomura (2025), these studies provide both methodological and theoretical foundations for analyzing how the EU's policy may have affected plastic waste exports, offering points of comparison to assess the magnitude, direction, and significance of trade diversion observed in this thesis.

This study aims to contribute to the existing literature by applying the gravity model to a new context: the effects of the 2021 EU plastic waste export ban. By building on the theoretical framework of Tinbergen (1962) and the methodological advancements of Silva and Tenreyro (2006) with Westerlund and Wilhelmsson (2011), this study contributes to understanding the trade dynamics surrounding environmental trade policies. The chosen estimation approach, with the use of fixed effects to control for unobserved heterogeneity and PPML estimations to handle zero trade flows, is grounded in the literature. Furthermore, the use of interaction terms to explore if the EU ban shifted trade patterns through a chain effect stems from most recent literature on trade policy (Adarov, 2023; Ishimura, Ichinose and Nomura, 2025).

# 4. Data and Methodology

This section outlines the data and empirical strategy employed to assess the impact of the EU 2021 plastic waste export ban to non-OECD countries on trade flows. The particular focus is on the role of fixed effects, interaction terms and regional dummies.

## 4.1 Data

This study utilizes bilateral trade data for plastic waste spanning 142 countries from 2017 to 2023. The data covers plastic waste within 3915 four-digit Harmonised System (HS) categories. My sample consists of unbalanced panel data comprimizing 2881 country-pairs with 122 exporting countries and 142 importing countries, resulting in a total of 20,085 observations covering the yearly plastic waste trade volume collected from UN Comtrade (2025). The data also includes geographical variables such as distance between capitals and common language, compiled from ('CEPII - GeoDist', 2025) and GDPs are compiled from World Development Indicators | DataBank (2025). Lists of EU and OECD memberships have been collected from (EU countries | European Union, 2025) and (OECD, 2025).

Table 1 summarizes the key characteristics of the dataset. To prevent considerable variation as the models apply fixed effects, all country-pairs with zero trades throughout the dataset have been removed. Each observation is a unique combination of exporter, importer, and year, showcasing the breadth of the study.

*Table 1. Descriptive Statistics of plastic waste data*

| Variable | Unit | Min | Mean | Max |
|---|---|---|---|---|
| Trade volume | Kilogram per year | 0 | 1397379 | 749,267,740 |
| Distance | Kilometers | 81 | 5,791 | 19,776 |
| Exporter GDP | USD (billion) | 3.2 | 430 | 18,000 |
| Importer GDP | USD (billion) | 0,045 | 430 | 18,000 |
| Common Language | Dummy | 0 | 0.93 | 1 |
| EU Exporter | Dummy | 0 | 0.17 | 1 |
| OECD Importer | Dummy | 0 | 0.23 | 1 |
| Post 2021 | Dummy | 0 | 0.42 | 1 |

There is significant variation in the distribution of the dataset, with a maximum value of traded volume reaching approximately 749 million kilograms, and mean values significantly lower, which indicates that the majority of the observed trade flows are relatively small in comparison to a few outliers. Exporter and importer GDP capture the GDP of exporting and importing countries, respectively. The values range widely from the lowest value of $45 million to the highest value of $17.9 trillion, reflecting the inclusion of both small and large economies. Distance measures the geographical distance in kilometres between the capitals of exporting and importing countries, and the values range from 81 km to approximately 20,000 km. The dataset also includes dummy variables that help account for institutional and cultural factors that could influence trade: EU exporter, OECD importer and Common language. By taking the value 1, the dummy variable indicates if an exporting country is an EU member, an importing country is an OECD member and whether the pair shares an official language. To assess the policy impact of trade flows, the dummy variable Post 2021, indicating whether the trade observation is prior to or after the ban, is used.

## 4.2 Model specifications

This study evaluates the impact of the 2021 EU export ban on plastic waste trade. I employ variants of the standard gravity model of trade. Using a DiD approach with interaction terms, the models investigate the effect of the ban based on institutional memberships of the exporting and importing countries. First, the baseline model is introduced as a reference model to capture the effects of key gravity model variables and the effects of institutional memberships on trade flows, while controlling for fixed effects. Building on Model (1), Models (2) and (3) introduce interaction terms to capture the differential effects of the ban between EU and OECD countries. As an alternative to fixed effect estimations, Model (4) introduces regional dummies to control for unobserved regional heterogeneity. Finally, Model (5) builds on the previous models and incorporates a complete set of interaction terms and exporter, importer and year fixed effects to capture the full effect of the ban.

### 4.2.1 Baseline Gravity Model of Trade

The empirical analysis in this study employs a gravity model of trade to capture the effects of distance, economic size, common language and institutional factors on bilateral trade flows of plastic waste. This model, originally proposed by Tinbergen (1962), has evolved significantly. It has advanced to control for multilateral resistance terms, a key development emphasised by Anderson and van Wincoop (2003). This traditional approach to estimating the gravity model, which involves taking logs of both sides to create a log-log model, ensures that G now becomes the constant $\beta_0$.

$$ln(F_{ij}) = \beta_0 + \beta_1 ln(M_i) + \beta_2 ln(M_j) - \beta_3 ln(D_{ij}) + \varepsilon_{ij} \qquad \textit{(Equation 2)}$$

Where $F_{ij}$ denotes volume of trade from country $i$ to country $j$, which is usually measured in kilograms or monetary value. $M_i$ and $M_j$ are usually indicators of a country's mass, which is typically measured by GDP or population. $D_{ij}$ denotes the distance in kilometres between country $i$ and country $j$, and $\varepsilon_{ij}$ is an error term with expectation equal to 1.

Since the dataset contains several zero trade flows, OLS estimator is not considered an appropriate model since it cannot handle $F_{ij}$ being equal to zero. Additionally, OLS estimations of gravity models are unable to address unobserved heteroskedasticity, which is why PPML is preferred over OLS to analyse bilateral trade flows using a gravity model of trade (Silva and Tenreyro, 2006).

## 4.3 Estimation Models

This study estimates five models with the PPML estimators with different fixed effects to assess the impact of the 2021 EU plastic waste export ban to non-OECD countries, relative to other trade flows.

### 4.3.1 PPML Gravity Model

The baseline estimating Model (1) follows the standard gravity equation, including GDPs, distance, dummies for common language, EU and OECD memberships and a post-2021 coefficient to capture the effects of the ban. Model 1 is expressed as:

$$X_{ijt} = exp\ [\beta_0 + \beta_1 log(Distance_{ij}) + \beta_2 log(GDP_{it}) + \beta_3 log(GDP_{jt}) + \beta_4 Common\ language_{ij} + \beta_5 EU_i + \beta_6 OECD_j + \beta_7 Post2021_t] + \varepsilon_{ijt}$$

*(Model 1)*

Where $X_{ijt}$ is the dependent variable for the bilateral trade volume in net weight in kilograms between exporting country $i$ and importing country $j$ at time $t$. To capture the transportational costs of trade between a country-pair, $log(Distance_{ij})$ the distance in kilometres between the exporter $i$ and importer $j$ is included. According to the traditional gravity model of trade, longer distance between two countries indicates increased transportation costs which would have a negative effect on trade (Tinbergen, 1963). The expected sign on distance is negative**.** Furthermore, $log(GDP_{it})$ is included to capture the economic size of the exporting country $i$ at time $t$ and $log(GDP_{jt})$ captures the economic size of the importing country $j$ at time $t$. Tinbergen (1963) argues that economic size is a driver of trade, and both are expected to be positive and significant at the 5 % percent level. Anderson and van Wincoop (2003) further argue that cultural factors impact bilateral trade flows. The dummy variable $Common\ language_{ij}$ takes the value 1 if the export and import share a common official language, and 0 otherwise. $Common\ language_{ij}$ is expected to have a positive sign since shared language could indicate colonial ties and reduced translation costs.

To capture the effect of institutional memberships, the dummy variables $EU_i$ and $OECD_j$ are included. $EU_i$ takes the value 1 if the exporting country is a member of the EU and 0 otherwise. Similarly, $OECD_j$ takes the value 1 if the importing country is a member of the OECD. Since the EU trade ban only applies to waste exports from EU countries to non-OECD countries, the $EU_i$ dummy is only applied to exporting countries and the $OECD_j$ dummy only applies to importing countries in this dataset. Finally, $Post2021_t$ is a dummy variable that takes the value 1 if the observation is after the implementation of the ban in 2021, and 0 otherwise. I expect that EU membership and OECD membership have a positive effect on trade flows, while the period after the ban is expected to reduce trade flows.

### 4.3.2 PPML Gravity Model with Fixed Effects

Building on Model (1), I introduce interaction terms in Model (2) and (3) to investigate how the effect of the 2021 EU ban varies between exporters and importers while controlling for exporter and time-specific effects in Model (2) and importer and time-specific effects in Model (3).

Model (2) is specified as:

$$X_{ijt} = \exp\,[\beta_0 + \beta_1 log\left(Distance_{ij}\right) + \beta_2 log(GDP_{it}) + \beta_3 log\left(GDP_{jt}\right) + \beta_4 Common\ language_{ij} + \beta_5 EU_i + \beta_6 OECD_j + \beta_7 Post2021_t + \beta_8 + \beta_8(EU_i \times Post2021_t) + \beta_9\left(OECD_j \times Post2021_t\right) + \beta_{10}\left(EU_i \times OECD_j \times Post2021_t\right) + \delta_i + \delta_t] + \varepsilon_{ijt} \quad \textit{(Model 2)}$$

And Model (3) is expressed as:

$$X_{ijt} = \exp[\beta_0 + \beta_1 log\left(Distance_{ij}\right) + \beta_2 log(GDP_{it}) + \beta_3 log\left(GDP_{jt}\right) + \beta_4 Common\ language_{ij} + \beta_5 EU_i + \beta_6 OECD_j + \beta_7 Post2021_t + \beta_8 + \beta_8(EU_i \times Post2021_t) + \beta_9\left(OECD_j \times Post2021_t\right) + \beta_{10}\left(EU_i \times OECD_j \times Post2021_t\right) + \delta_j + \delta_t] + \varepsilon_{ijt} \quad \textit{(Model 3)}$$

The additional variables from Model (1) are the interaction terms $(EU_i \times Post2021_t)$, $\left(OECD_j \times Post2021_t\right)$ and, $\left(EU_i \times OECD_j \times Post2021_t\right)$ in Models (2) and (3), respectively. The interaction term $(EU_i \times Post2021_t)$ is included to capture the effect of the ban on EU exports after its implementation in 2021. As the trade ban disallows trade, I expect a reduction in trade flows from EU exporters post-ban, as a reflection of the reduced potential trade partners for EU countries after 2021. However, since the restriction is applied to trade destinations rather than volume, the 2021 export ban might not have a significant effect on the trade volumes of plastic waste. To capture how the ban affected importing volumes for OECD countries, the interaction term $\left(OECD_j \times Post2021_t\right)$ is included. Since the EU ban does not necessarily reduce the volume of plastic waste exported from EU countries, the total trade volume may remain the same, instead EU countries shift the destination of these exports. As the EU ban implies that OECD member states are the only eligible importer group, suggesting that previous trade flows between the EU and non-OECD countries will re-route to trade flows between the EU and OECD countries only. Thereby, I expect an increase in imported volume of plastic waste for OECD countries.

The triple interaction term $(EU_i \times OECD_j \times Post2021_t)$ is the main coefficient of interest in Model (2) as it captures the combined effect of the EU export restriction, the status of OECD membership for importers, and the post-ban period, year 2021, relative to other trade flows. In particular, the triple interaction term captures the magnitude of increased imports of plastic waste for OECD countries from EU countries after the ban in 2021, as they absorb the rerouted trade that went to non-OECD countries before the ban. Since the EU export ban prohibits EU exports to non-OECD countries, I expect an increased flow of waste between EU countries to OECD countries after the ban, relative to other trade flows.

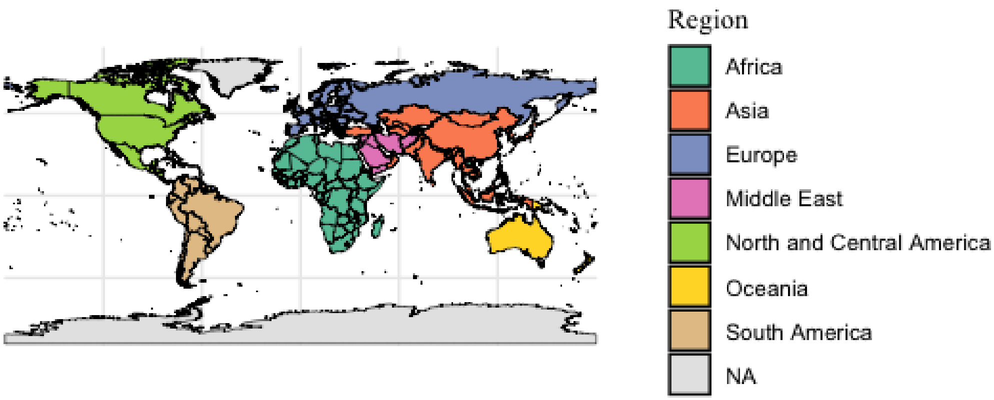
Model (2) includes exporter and year fixed effects, where $\delta_i$ the exporter fixed effect controls for exporting country-specific factors that can influence trade flows from the exporting countries. Such factors could be domestic policies, regulations or level of development, and $\delta_t$ is the time fixed effects for each year t to control global trends that might influence trade. By including two-way fixed effects, Model (2) controls for unobserved exporter and time heterogeneity that could influence the observed trade patterns. This leads to a more accurate estimate of the relationship between trade determinants and trade flows (Herman, 2023). Similarly, the importer and year fixed effects in Model (3) control for unobserved exporter and time heterogeneity that could influence the observed trade patterns.

### 4.3.3 Gravity model with regional dummies

As an alternative to the more granular fixed effects that are typically included in gravity models, Model (4) focuses on the use of regional dummies instead. This model is employed to account for regional variations in trade flows while avoiding the challenges associated with incorporating a large number of fixed effects, such as multicollinearity and overfitting. In international trade analysis, regional dummies can be used for geographic or economic differences between countries that could influence bilateral trade relationships (Anderson and van Wincoop, 2003; Carrère, 2006; Frankel, 1998). They elaborate on the idea that countries within the same region share trade policies, cultural ties, similar economic structures, and geographic proximity can significantly impact trade flows. Regional dummies group countries by their geographic characteristics and assign each group a separate intercept, allowing for capturing regional trade patterns. Thus, by including regional dummies, Model (4) aims to capture broad regional effects that can explain differences in trade patterns across countries. It also allows for a better fit to the data by separating intra-regional and inter-regional trade dynamics. The regional dummies for this Model represent distinct groups of countries based on geographic and cultural criteria.

Countries are thus grouped into the following regions:

*Figure 3. Regional Groups*




*Note: This figure illustrates the world's sovereign countries grouped into seven regions: Oceania, South America, North and Central America, Middle East, Europe, Asia, and Africa. Countries not included in the regional classification are shown in grey. Colors indicate region membership to facilitate visual comparison of geographical distribution.*[2]

Model (4) with regional dummies is an alternative to the fixed effect estimations. While the various sets of fixed effects estimations capture much of the heterogeneity, comparing the results with a regional dummy estimation provides additional granularity and robustness. While the fixed effects for exporter, importer, and time, used in Models (2), (3), and (5), control for unobserved heterogeneity at the country level, regional dummies account for regional patterns.

Model (4) is expressed as:

$$X_{ijt} = exp\ [\beta_0 + \beta_1 log(Distance_{ij}) + \beta_2 log(GDP_{it}) + \beta_3 log(GDP_{jt}) + \beta_4 Common\ language_{ij} + \beta_5 EU_i + \beta_6 OECD_j + \beta_7 Post2021_t + \beta_8 (EU_i \times Post2021_t) + \beta_9 (OECD_j \times Post2021_t) + \beta_{10} (EU_i \times OECD_j \times Post2021_t) + \beta_{11} Europe_i + \beta_{12} NorthAmerica_i + \beta_{13} SouthAmerica_i + \beta_{14} Asia_i + \beta_{15} Africa_i + \beta_{15} MiddleEast_i + \beta_{15} Ocenia_i + \beta_{15} Europe_j + \beta_{12} NorthAmerica_j + \beta_{16} SouthAmerica_j + \beta_{17} Asia_j + \beta_{18} Africa_j + \beta_{19} MiddleEast_j + \beta_{20} Ocenia_j] + \varepsilon_{ijt} \quad \text{(Model 4)}$$

Where the variables $log(Distance_{ij})$, $log(GDP_{it})$, $log(GDP_{jt})$, $Common\ language_{ij}$, $EU_i$, $OECD_j$, $Post2021_t$ and interaction terms $(EU_i \times Post2021_t)$, $(OECD_j \times Post2021_t)$ and $(EU_i \times OECD_j \times Post2021_t)$ are interpreted as in Models (1), (2), and (3). The additional variables are the regional dummies for exporting and importing countries, respectively. The $Europe_i$ regional dummy takes the value 1 if the exporting country i is located in

[2] Regions correspond to the groupings used in the alternative Model 4 (see Section 4.3.3). For a complete list of countries and their corresponding region groups, see Appendix 3. Country classification follows the same grouping used for constructing the dummy variables in the empirical analysis.

Europe, and 0 otherwise. $NorthAmerica_i$, $SouthAmerica_i$, $MiddleEast_i$, $Asia_i$, $Africa_i$ and $Ocenia_i$ will take the value 1 if the exporting country i is located in North America, South America, Middle East, Asia, Africa and Ocenia, respectively. The regional dummy variables for the importing countries, j, behave the same.

Geographical proximity and regional economic integration are both important factors that may influence international trade dynamics. The intuition stems from that countries within the same region are often involved in Regional Trade Agreements (RTAs) or benefit from economic or political ties, encourage higher trade flows. For instance, the EU members engage in significant intra-regional trade due to shared policies, currency (in some cases) and shared regulatory frameworks. Countries outside of such RTA however, may face higher trade costs due to tariffs, barriers or other obstacles. Nevertheless, regional agreements improve the accuracy of the gravity model or other factors that are specific to bilateral trade flows (Anderson and van Wincoop, 2003). Including the regional dummies allows Model (4) to account for trade flows between countries that are geographically and culturally closer and thereby more likely to engage in trade.

### 4.3.4 Gravity Model with Exporter, Importer and Year Fixed Effects

The final model that is presented in this study combines exporter, importer and, year fixed effects with three interaction terms. Building on the insights from the baseline Model (1) and the interaction Models (2) and (3) with two-way fixed effects, the final Model (5) is the most robust specification as it accounts for exporter and importer-specific characteristics over time.

The final empirical model used to estimate the effects of the EU plastic waste ban on trade dynamics is expressed as follows:

$$X_{ijt} = exp\,[\beta_0 + \beta_1 log(Distance_{ij}) + \beta_2 log(GDP_{it}) + \beta_3 log(GDP_{jt}) + \beta_4 Common\ language_{ij} + \beta_5 EU_i + \beta_6 OECD_j + \beta_7 Post2021_t + \beta_8 + \beta_8(EU_i \times Post2021_t) + \beta_9(OECD_j \times Post2021_t) + \beta_{10}(EU_i \times OECD_j \times Post2021_t) + \delta_i + \delta_j + \delta_t] + \varepsilon_{ijt} \qquad \textit{(Model 5)}$$

Similarly to the baseline gravity variables from Model (1) and the interaction terms from Models (2) and (3), the expected signs remain. The exporter, importer and year, fixed effects estimation in Model (5), $\delta_i$, $\delta_j$ and $\delta_t$ is a central feature of this model. The exporter fixed effect $\delta_i$, account for unique exporter characteristics that are not captured by any of the independent variables, yet still might influence trade. Similarly, importer and year fixed effects account for similar unobservable characteristics for importer and year, respectively.

Recent literature often include country-pair or bilateral fixed effects to account for country-pair specific factors, which in combination with year fixed effects is considered the most robust approach in trade studies (Anderson, Larch and Yotov, 2018: Anderson and Yotov, 2016; Head and Mayer, 2014; Westerlund and Wilhelmsson, 2011). The three-way fixed effect comes with a central limitation in the context of this study as the fixed effects will absorb all time-invarying country-pair characteristics, due to multicollinearity. Since this study aims to investigate trade dynamics through the lens of the traditional gravity variables, including a three-way fixed effect estimation will limit this opportunity. The variable $log(Distance_{ij})$, for instance, will be absorbed by country-pair fixed effects since the distance in kilometers between Sweden and Finland remain constant over years, and thereby collinear with the fixed effects. However, when we control for exporter characteristics, there will be variation in $log(Distance_{ij})$ between the exporting countries, and the coefficient will still be interpretable. Since several studies (Anderson, Larch and Yotov, 2018: Anderson and Yotov, 2016; Head and Mayer, 2014; Westerlund and Wilhelmsson, 2011) argue that country-pair fixed effects is best practice to account for MRTs, a three-way fixed effects model will be used in this study as a robustness check (see Appendix 6).

# 5. Results

This section will present the empirical findings of this study. To examine the effects of the EU's plastic waste export restrictions on overall trade, a gravity model of trade has been estimated using PPML, following the recommendations of Santos Silva and Tenreyro (2006). The usage of PPML ensures consistent estimations despite the presence of zero trade values in the dataset, which is of great importance in this particular context. For robustness, various versions of the PPML estimator of the gravity model of trade were estimated, and the selected results are reported in Table 2. Results of the main estimation Model (5) are presented separately in Table 3.

While the triple interaction term between EU exporter status, OECD importer status and the post-2021 period is negative across all four models, it is not statistically significant in models that include fixed effects. The results from the interaction terms should therefore be interpreted as suggestive rather than conclusive. The main estimation model in this study is Model (5), which incorporates exporter, importer and year fixed effects simultaneously and thereby provides the most stringent control for unobserved heterogeneity. The traditional gravity variables - distance, GDP, and language - remain statistically significant with the expected signs. The triple interaction term is negative and statistically insignificant, implying that after accounting for all exporter, importer and year specific shocks, Model (5) cannot show that the EU ban has an apparent measurable effect on trade.

## 5.1 Empirical results

Table 2 reports the results of the PPML estimation for estimating Models (1-4). Column 1 in Table 2 presents the baseline Model (1) without interaction terms and fixed effects. Columns 2-4 present PPML estimations of the gravity model with different sets of fixed effects to control for unobserved heterogeneity. Column 2 presents Model (2) with interaction terms with exporter and year fixed effects.

Including exporter and year fixed effects in Model (2) leads to the removal of $EU_i$ and $Post2021_t$, due to multicollinearity (Adarov, 2023; Helpman, Melitz and Rubinstein, 2008; Ishimura, Ichinose and Nomura, 2025). Similar to Adarov (2023) and Ishimura, Ichinose and Nomura (2025), their effect will be estimated through interaction terms. This logic applies to Models (2-5). Column 3 presents Model (3), where importer and year fixed effects are used. As an alternative to the fixed effects panel estimations, Model (4) includes regional dummies to control for regional characteristics (see Appendix 3). The results of Model (4) are presented in Table 2, column 4.

*Table 2. PPML Estimation Results of the Gravity Model of Trade*

| Variable | Model (1) | Model (2) | Model (3) | Model (4) |
|---|---|---|---|---|
| Common language | 1.330*** | 1.517*** | 1.450*** | 1.506*** |
| | (0.253) | (0.363) | (0.238) | (0.081) |
| *log*(Distance) | -1.128*** | -1.015*** | -1.164*** | -1.086*** |
| | (0.062) | (0.061) | (0.125) | (0.039) |
| *log*(GDP exporter) | 0.694*** | 1.053*** | 0.738*** | 0.693*** |
| | (0.088) | (0.318) | (0.082) | (0.029) |
| *log*(GDP importer) | 0.665*** | 0.588*** | -2.672*** | 0.587*** |
| | (0.030) | (0.058) | (0.688) | (0.104) |
| EU*i* | 0.418 | | 0.537 | -0.478*** |
| | (0.243) | | (0.450) | (0.088) |
| OECD*j* | -0.856*** | -1.560*** | | -1.644*** |
| | (0.182) | (0.202) | | (0.387) |
| Post 2021 | -0.374*** | | | |
| | (0.084) | | | |
| EU*i* × Post 2021 | | 0.161 | 0.342 | 0.236** |
| | | (0.316) | (0.319) | (0.091) |
| OECD*j* × Post 2021 | | 0.838*** | 0.787*** | 0.918** |
| | | (0.212) | (0.200) | (0.319) |
| EU*i* × OECD*j* × Post 2021 | | -0.274 | -0.409 | -0.340** |
| | | (0.335) | (0.347) | (0.124) |
| Observations | 20,085 | 20,085 | 20,085 | 19,540 |
| Exporter FE | No | Yes | No | No |
| Importer FE | No | No | Yes | No |
| Year FE | No | Yes | Yes | Yes |
| Regional dummies | No | No | No | Yes |

*Note:Coefficients marked with *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the exporter level and reported in parentheses.*

Distance exhibits a consistently negative and highly significant effect on trade across all models. In Model (1), the negative and significant coefficient implies that a one percentage increase in bilateral distance is associated with approximately a 68% reduction in trade flows. The results are expected and consistent with the canonical gravity model (Head and Mayer, 2014). The magnitude remains roughly similar in the remaining Models (2-4), which indicates robustness to the inclusion of exporter, importer and year-specific heterogeneity. A slight increase in Model (5) where distance exhibits a highly significant negative effect with approximately 71% reduction, which is consistent across models. This supports the classical “friction of distance” mechanism in trade (Anderson and van Wincoop, 2003;

Tinbergen, 1963), suggesting that longer transport distances significantly reduce the likelihood or volume of plastic waste trade.

The GDP coefficients for exporting and importing countries help display more nuanced patterns. Exporter GDP remain positive and highly significant across all models, as expected, while its magnitude varies across models. The GDP exporter coefficient in Model (1) is reflecting the expected positive relationship that larger economies generate more exports (Tinberg, 1962). When including exporter and year fixed effects in Model (2), the isolated time-varying impact of the coefficient increases to 186%. In contrast, when controlling for importer and year unobserved heterogeneity, the GDP coefficient for the exporter is 109%, which reflects a balance between exporter heterogeneity and importer-specific controls. Importer GDP also follow expected patterns. The negative effect of importer GDP in Models (3) and (5) seems counterintuitive at first. As Model (3) includes importer and year fixed effects, the fixed effects may absorb much of the positive variation associated with importer size, thus leaving only residual variation that sometimes leads to negative point estimates. The GDP coefficents in the main Model (5) follow the same patterns. Exporter GDP is positive and statistically significant, confirming that larger EU economies export 161% more plastic waste and importer GDP is negative and significant. This contrast may reflect a niche trade pattern in which smaller importing markets often specialized recycling facilities thus, receive a larger relative share of EU plastic waste. The negative effect, while counterintuitive for conventional goods trade, is consistent with literature on specialized environmental goods, where smaller markets often dominate due to regulatory or technical capacities (Ishimura, Ichinose and Nomura, 2025). The results of this coefficient must be interpreted with caution. Sharing a common language has a positive and significant coefficient across all models, indicating that shared language facilitates trade by reducing transaction and coordination costs. The estimates in Model (5) suggest that countries that share a common language trade almost 322% more, compared to countries who do not share a language. This aligns with prior gravity studies emphasizing cultural and institutional proximity (Head and Mayer, 2014; Rose, 2004).[3]

EU membership (on exporting countries) and OECD membership (on importing countries) are included to capture their effect on trade patterns after the EU export ban. The dummies $EU_i$, $OECD_j$ and $Post2021_t$ are mainly interpreted through their

[3] Coefficients from the Poisson Pseudo-Maximum Likelihood (PPML) estimations are reported as percentage changes for ease of interpretation. This is calculated by exponentiating each estimated coefficient, subtracting one, and multiplying by 100 (i.e., % change = [exp(β) − 1] × 100). For interaction terms, the percentage change represents the combined effect of all relevant coefficients, meaning the sum of the main effect and interaction coefficients is exponentiated before converting to a percentage. This allows for an intuitive interpretation of how a one-unit change in the explanatory variable (or combination of variables for interactions) impacts the expected trade flow, conditional on the fixed effects included in the model. See Appendix 6.

interaction terms. Model (1) captures the main effects of their impact on trade dynamics, where an exporting country being part of the EU is positive at 52% but not statistically significant. Being an OECD member for the importing country significantly reduces trade by 57%, but these baseline effects are less informative due to the potential unobserved heterogeneity. The inclusion of exporter and year fixed effects in Model (2) leads to the removal of $EU_i$ and $Post2021_t$ due to multicollinearity (Adarov, 2023; Helpman, Melitz and Rubinstein, 2008; Ishimura, Ichinose and Nomura, 2025). Similar to Adarov (2023) and Ishimura, Ichinose and Nomura (2025), their effect will be estimated through interaction terms. The main coefficients of interest (interaction terms) are tested through Models (2-5) with different sets of fixed effects for robustness. The main coefficient of interest is the triple interaction term in the main Model (5). The interaction term $\left(OECD_j \times Post2021_t\right)$ is consistently positive and significant in Models (2-5), indicating that EU exporters maintained and/or slightly shifted trade flows toward OECD countries after the implementation of the ban in 2021. These results were expected and supports partial substitution effects, consistent with theoretical expectations and prior empirical studies on environmental trade restrictions (Copeland & Taylor, 2004; Ishimura, Ichinose and Nomura, 2025). In contrast to previous literature, OECD memberships do not serve as a proxy for institutional resistance. In this context, the OECD dummy is interpreted as a direct reflection of the legal constraints imposed by the ban. When capturing EU-specific exports response to the ban, the interaction term $(EU_i \times Post2021_t)$ is smaller in magnitude and insignificant when fixed effect applies. The exception is Model (4), including regional dummies. These results indicate that the regional dummies capture part of the adjustment, and the residual effect of EU membership itself is modest.

After the 2021 EU ban, EU exporters are expected to redirect plastic waste exports toward OECD countries. The main coefficient of interest is the triple interaction $\left(EU_i \times OECD_j \times Post2021_t\right)$ in Model (5), Table 3. This variable captures the differential effect on flows specifically from EU exporters to OECD importers after 2021, relative to the period before 2021. While the triple interaction term remains negative across all models from Tables 2 and 3, it is only statistically significant in Model (4), column 4, in Table 2. The negative coefficient suggests a slightly lower increase in traded plastic waste from EU countries to OECD countries after 2021, compared to the increase from non-EU countries to non-OECD countries before 2021. These results have to be interpreted cautiously, as they are not significant. Because of the insignificant values in most models, the evidence is insufficient to conclude a definitive change relative to the pre-2021 baseline and the coefficient should be interpreted as indicative but inconclusive evidence of a potential trade adjustment mechanism.

The results of the main model is presented in table 3.

*Table 3. Results of PPML Gravity Model of Trade with exporter, importer and year Fixed Effects*

| Variable | Model (5) |
|---|---|
| Common language | 1.592*** |
| | (0.362) |
| *log*(Distance) | -1.251*** |
| | (0.141) |
| *log*(GDP exporter) | 0.959** |
| | (0.346) |
| *log*(GDP importer) | -2.598*** |
| | (0.683) |
| EU*i* × Post 2021 | 0.213 |
| | (0.324) |
| OECD*j* × Post 2021 | 0.365** |
| | (0.400) |
| EU*i* × OECD*j* × Post 2021 | -0.289 |
| | (0.361) |

*Note:Coefficients marked with *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the exporter level and reported in parentheses. Fixed effects for exporter, importer and year are included to account for unobserved heterogeneity.*

## 5.2 Robustness checks

### 5.2.1 Comparison across Models and Fixed Effects

As expected, certain variables were removed in the estimation process due to multicollinearity with fixed effects. This is a common feature in highly saturated gravity models with extensive fixed effects (Fernández-Val and Weidner, 2016; Westerlund and Wilhelmsson, 2011). Importantly, the removal of these variables does not compromise the estimation of interaction terms; instead, it ensures that identification comes from within-group variation and cross-country-year differences. Nevertheless, this highlights the limitation of separately identify the main effects of EU or OECD membership independently of fixed effects, and my interpretations focus on relative changes captured by interactions. The regional dummy specifications in Model (4) further support these insights. While coefficients on some region-specific interactions differ in magnitude, their statistical insignificance mirrors the modest and heterogeneous response of the EU waste trade. These results reinforce the notion that structural factors, such as distance, language, and economic size, continue to dominate trade outcomes even under regulatory constraints, echoing findings from broader gravity-model applications (Anderson, 2011; Baier and Bergstrand, 2007; Head and Mayer, 2014).

A three-way fixed effects Model (6) have been conducted to test the robustness of Model (5), (see Appendix 6). While country-pair fixed effects is the most robust application in panel data gravity models as it controls for bilateral-specific characteristics, this study aims to analyse the effects of the EU ban on EU exports to OECD countries, in relation to other trade flows. As mentioned earlier, including country-pair fixed effects limits the potentioal to interpret some traditional gravity variables, due to multicollinearity. Comparing the results of the interaction terms in Model (5) and Model (6), allows me to observe how the results varies with different sets of fixed effects.

Nevertheless, the direction and significance of the triple interaction terms from Model (5) and Model (6) align and the variation in magnitude is small. This suggest that the effect of EU's 2021 export ban on EU exports to OECD importers relative to other trade flows, is not changing with country-pair fixed effects.

### 5.2.2 Placebo Test: Aluminum trade flows

To strengthen the credibility of the DiD approach, a placebo test was conducted using aluminum trade flows, a commodity that is not directly affected by the 2021 EU plastic waste regulation but is otherwise traded under similar international conditions.

This exercise allows me to assess whether post-2021 changes observed in plastic waste trade might be driven by general trade dynamics rather than the regulatory intervention. Consistent with the main analysis, aluminum trade flows were aggregated by exporter and importer pairs over the period 2017 to 2023, with EU exporter and OECD importer dummies included. The same PPML estimation procedure, incorporating exporter, importer, and year fixed effects, was applied to the aluminum dataset, mirroring the structure of the primary plastic waste model. This ensures that any differences in trade patterns are comparable and that the parallel trends assumption underlying the DiD identification is rigorously evaluated. Zero trade flows were added explicitly to ensure a complete representation of all possible bilateral trade relationships, consistent with the methodology applied to plastic waste.

The results of the Aluminum Model is presented in Table 4.

*Table 4. Results of comparison model with aluminum data*

| Variable | Estimate |
|---|---|
| *log*(Distance) | -1.558*** |
| | (0.127) |
| *log*(GDP exporter) | -0.369 |
| | (0.491) |
| *log*(GDP importer) | -1.161** |
| | (0.407) |
| EU*i* × Post 2021 | -0.005 |
| | (0.144) |
| OECD*j* × Post 2021 | -0.306** |
| | (0.110) |
| EU*i* × OECD*j* × Post 2021 | -0.012 |
| | (0.161) |

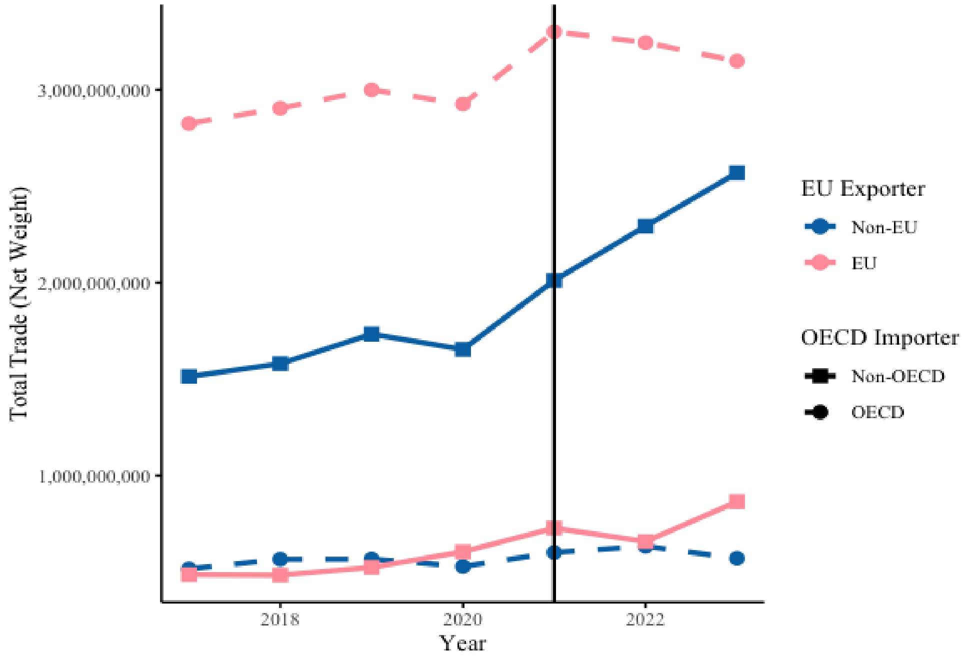
*Note:Coefficients marked with *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the exporter level and reported in parentheses. Fixed effects for exporter and importer are included to account for unobserved heterogeneity.*

The results in Table 4[4] indicate that the effect of the triple interaction term between $(EU_i \times OECD_j \times Post2021_t)$ is insignificant, mirroring the patterns observed for plastic waste in Table 3. Overall, the aluminum results largely replicate the directional effects observed for plastic waste, but differ in magnitude and the significance of GDP effects. The findings of the comparison waste analysis support the robustness of the main results.

Furhtermore, a visualised presentation of the evolution of aluminum trade flows between 2017 and 2023, disaggregated by EU exporter and OECD importer status, is shown in Figure 4.

[4] *Note:* The table reports results from a Poisson Pseudo-Maximum Likelihood (PPML) estimation of bilateral aluminum trade flows. The sample includes 118 exporters, 134 importers, and 7 years (2017–2023), including country-pairs with zero trade flows. The model includes exporter, importer, and year fixed effects, and standard errors are clustered at the exporter level. Interaction terms capture the effect of EU exporter membership, OECD importer membership, and post-2021 trade dynamics. This model is included as a comparative robustness check alongside the main plastic waste analysis.

*Figure 4. Aluminum Waste Trade Flows*

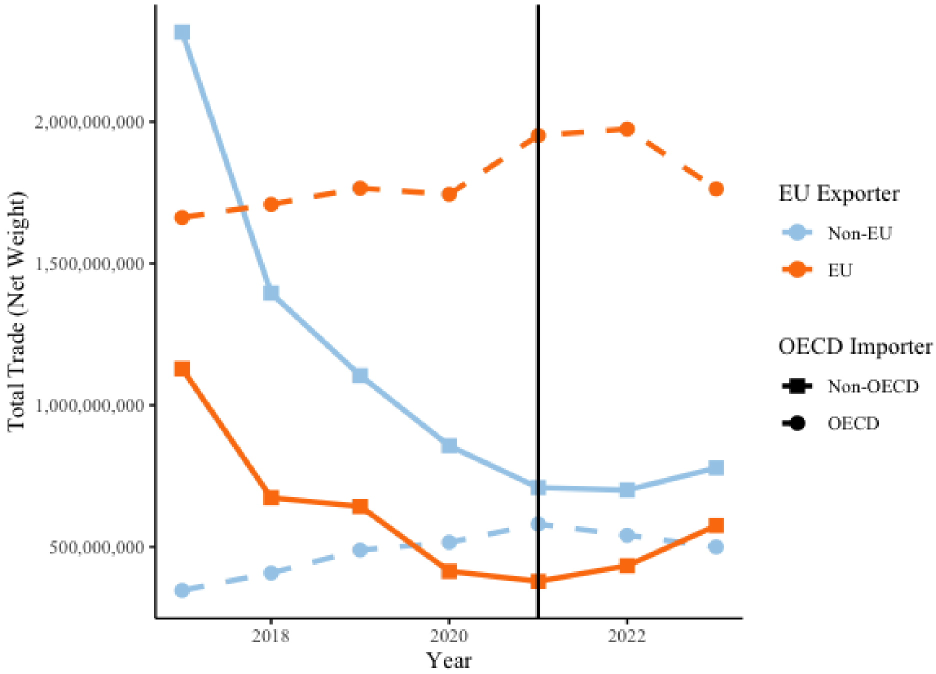



*Note: This figure presents annual aluminum waste trade flows (net weight) for all sovereign country pairs between 2017 and 2023. Exporters that are EU members are shown in red, while non-EU exporters are shown in blue. OECD importers are represented with dashed lines, and non-OECD importers with solid lines. The vertical line indicates the year 2021, corresponding to the implementation of the EU plastic waste ban. Aluminum trade flows do not exhibit a systematic change after 2021, suggesting that observed shifts in plastic waste trade post-2021 are unlikely to be driven by broader trade trends and supporting the parallel trends assumption underlying the DiD analysis.*

Aluminum flows exhibit no systematic post-2021 shift, and trends across treatment and control groups remain parallel, confirming that macroeconomic shocks or general trade patterns are unlikely to explain changes observed in plastic waste trade. This placebo exercise supports the validity of the parallel trends assumption underpinning the PPML DiD analysis.

Figure 5 illustrates a visualised presentation of the evolution of plastic waste trade flows between 2017 and 2023, disaggregated by EU exporter and OECD importer status.

*Figure 5. Plastic Waste Trade Flows*




*Note: This figure presents annual plastic waste trade flows (net weight) for all sovereign country pairs between 2017 and 2023. Exporters that are EU members are shown in orange, while non-EU exporters are shown in blue. OECD importers are represented with dashed lines, and non-OECD importers with solid lines. The vertical line indicates the year 2021, corresponding to the implementation of the EU plastic waste ban.*

# 6. Discussion

The objective of this study is to examine the effect of the 2021 EU plastic waste export ban on EU exports to OECD countries, relative to other trade flows. In particular, this study aims to quantify whether trade flows from EU exporters to OECD importers decreased after the ban, through the lens of the traditional gravity model of trade. By using a PPML gravity model framework with multiple fixed effects specifications, I have been able to assess the nuances of trade responses while controlling for exporter, importer and year heterogenenity. This section discusses the results in terms of interpretation of policy effects and contributions for future research.

## 6.1 Interpretation of policy effects

The 2021 EU ban represents a targeted restriction that prevents EU exporters from sending plastic waste to non-OECD countries, aiming to redirect trade flows toward OECD importers. The triple interaction term $(EU_i \times OECD_j \times Post2021_t)$ captures this redirection relative to the pre 2021 period and other trade flows of non EU exporters. Across the main specifications, the coefficient for this interaction term is negative but not statistically significant. This result suggest that, while EU exports to OECD countries may have experienced a modest reduction of around 25%, there is substantial uncertainty surrounding this effect. This result implies that EU exporters were either able to partially substitute lost trade to non-OECD partners with new flows to OECD importers or that other factors, such as regulatory compliance costs, logistical constraints, or pre-existing trade relationships that mitigated the expected shifts. This pattern is broadly consistent with prior findings in related contexts: Li and Takeuchi (2023) find that China's 2017 waste import ban led to significant reductions in targeted flows, while Kellenberg and Levinson (2014) show that international environmental agreements can redirect environmentally sensitive trade with heterogeneous effects. Similarly, Ishimura, Ichinose, and Nomura (2025) find that while international agreements on plastic waste can induce shifts in trade patterns, these effects are often modest and uneven across regions, which resonates with the relatively muted relative reallocation observed in the EU context. Compared to these cases, the EU ban appears to have more subtle short-term effects, potentially reflecting the relatively high environmental and institutional standards among EU trading partners and the already regulated nature of EU waste exports. Overall, these comparisons suggest that while regulatory interventions can influence trade patterns, the immediate observable effects on EU plastic waste exports are limited and highly dependent on partner characteristics.The non-significance of the interaction term should be interpreted cautiously. In economic research, particularly in studies of trade policy, null results do not imply the absence of effect, but rather highlight heterogeneity, measurement limitations, or insufficient statistical power. In this context, bilateral trade flows in plastic waste are highly volatile and influenced by multiple unobserved factors, including local recycling capacity, market demand, and enforcement practices, which may dampen or obscure the measurable impact of policy. The non-significance may also reflect the fact that EU exporters had a relatively narrow set of OECD destinations to substitute toward, limiting the overall observable change.

The two-way interaction terms $(EU_i \times Post2021_t)$ and $\left(OECD_j \times Post2021_t\right)$ help disentangle the general effects of the ban. While these coefficients provide partial evidence that OECD importers experienced increased demand for EU plastic waste exports, the magnitude varies across specifications and is sometimes statistically insignificant. This finding is consistent with prior literature on trade restrictions, which emphasizes that policy shocks often produce heterogeneous responses that depend on the characteristics of both exporters and importers (Bown, 2021; Felbermayr et al., 2020). In other words, some EU exporters may have successfully redirected trade, while others experienced logistical or regulatory constraints that prevented substantial reallocation. Similarly, studies on trade agreements and regional integration provide context for interpreting heterogeneous policy effects. Baier and Bergstrand (2007) show that trade agreements generally increase trade flows, but the magnitude varies across partners and sectors due to existing trade networks and economic complementarities. In this case, EU exporters' ability to redirect plastic waste exports toward OECD importers appears constrained by limited alternative partners and structural factors, producing the heterogeneous responses captured by Model (5).

Methodologically, this study use the PPML framework with multiple fixed effects builds on best practices in gravity modeling (Anderson, Larch, and Yotov, 2018; Silva and Tenreyro, 2006). This is particularly relevant given the presence of zero trade flows and highly skewed bilateral trade data, which are common in the waste trade sector (Martin and Pham, 2020). The results on traditional gravity determinants such as distance, GDP, and shared language, align closely with the broader gravity literature (Anderson, 2011; Head and Mayer, 2014), reinforcing confidence that the observed policy effects are measured against a structurally consistent baseline. Finally, the finding that the main policy interaction term is not statistically significant is consistent with the broader literature on environmental trade restrictions. For example, Copeland and Taylor (2004) emphasize that bans or tariffs often produce substitution effects or delays in trade adjustments, rather than immediate reductions in trade volumes. The results of this study extend this insight to the 2021 EU plastic waste ban, demonstrating that even a highly targeted regulatory intervention interacts with pre-existing trade patterns, transport costs, and network effects, yielding modest and heterogeneous responses.

In addition to the three-way fixed effects Model (6), plastic waste trade patterns have been compared with the alternative commodity, aluminim waste, providing a visual and contextual control for interpreting the plastic waste trends. Figure 4 illustrates that, similar to plastic waste, aluminum flows remain stable throughout the 2017-2023 period. Thus suggest that the modest changes observed in Model (5) are unlikely to be driven by broad macroecnonomic or trade shocks affecting all materials. The comparative analysis underscores that the absence of drastic changes in plastic waste flows after 2021 does not necessarly imply the results are spurios. It can rather indicate that the observed trade patterns are subtle and gradual, potentially highlighting the limited immediate effect of policy or market shocks within the studied period. By contrasting with aluminum, it becomes evident that the trends it plastic waste flows are merely a reflection of general trade patterns, but instead signal material-specific behaviour.

## 6.2 Policy Implications

The findings of this study offer several insights for policymakers. First, targeted bans can redirect trade flows without necessarily causing large immediate reductions in overall exports, particularly when alternative destinations exist. Second, the uncertainty and heterogeneity in responses underscore the importance of complementary policies, such as support for compliance, infrastructure investment, and monitoring to ensure that environmental objectives are met without unintended trade disruptions. Third, the analysis highlights the value of maintaining high-quality trade and environmental data, which are essential for evaluating the effects of policy interventions.

# 7. Limitations

Several limitations should be acknowledged. First, the PPML estimator assumes conditional mean independence. While it addresses zero trade flows and heteroskedasticity, it cannot fully account for unobserved factors that may systematically affect trade flows. In other words, it assumes that, conditional on the explanatory variables, the expected value of the dependent variable is correctly specified. However, the PPML retains consistent estimates of the conditional mean even if the variance is mis-specified, which gives it better statistical properties than alternative approaches such as the negative binomial model in many empirical settings (Wooldridge, 2010). This robustness is particularly valuable in trade data, where the presence of zeros and significant variation across country-pairs can complicate estimation. Nevertheless, PPML cannot fully account for unobserved factors that may systematically affect trade flows, nor can it eliminate potential bias arising from omitted variables. Additionally, while the fixed effects framework used in this study controls for exporter, importer, and year-specific unobserved heterogeneity, it may absorb much of the variation in specific covariates, limiting the ability to identify their effects. Therefore, while the findings provide careful and methodologically grounded evidence on the effect of the EU plastic waste ban, they should be interpreted with appropriate caution, acknowledging the inherent limitations of any empirical model.

Second, the robustness checks have their own limitations. In addition to the main model, alternative specifications, including country-pair fixed effects models and a comparative commodity model using aluminium, were estimated. The country-pair fixed effects model is considered highly robust in the literature. However, it absorbs all bilateral gravity variables, meaning it fails to capture the effects of structural economic differences between countries. Likewise, while the aluminium analysis helps to ensure that observed patterns in plastic trade are not generalizable to all commodities, aluminium differs in its market regulatory and environmental characteristics. Thus, while these robustness checks strengthen confidence in the findings, they cannot eliminate uncertainty regarding the causal interpretation of the EU 2021 ban on plastic waste. Furthermore, sensitivity analyses across alternative fixed effect specifications showed minor variation in coefficient magnitudes, highlighting that small or insignificant coefficients, particularly the triple interaction term, should be interpreted with caution.

Third, data limitations constrain the precision and scope of the analysis. Detailed trade flows for niche waste commodities are often incomplete, which may contribute to imprecision in estimating the triple interaction term. Potential misclassification of plastic waste, unrecorded informal trade, or reporting errors may introduce noise and thereby limit the ability to detect small or subtle shifts in trade patterns. Another aspect of the data limitations stems from resource and computational constraints. Estimating PPML models with multiple high-dimensional fixed effects and a comparison waste model is computationally intensive. While successfully implemented in this study, expanding the analysis to longer periods, higher frequency data, or more specific waste categories may require substantial computing resources and a longer time frame. Furthermore, while the total number of observations in this study is large, the time period is relatively short post-ban. A short post-ban period may understate long-term adaptation in the EU waste export network. It is likely that the plastic waste trade adjustments take time due to contractual obligations, shipping logistics, and domestic processing constraints. As a result, the observed small and statistically insignificant triple interaction term coefficients may reflect delayed responses rather than any absence of trade shifts. Due to this temporal limitation and the insignificant triple interaction term coefficient, the interpretation of the results as evidence for any broader hypotheses, such as the Pollution Haven Hypothesis, should be done cautiously.

Fourth, the majority of policy-relevant interaction coefficients are not statistically significant, reflecting the high variability in trade responses and the relatively short post-ban period. Statistically insignificant coefficients indicate limited or inconclusive evidence of systematic shifts, rather than a failure of the model. This observation aligns with prior literature documenting modest responses to environmental trade interventions in early post-policy periods (Copeland and Taylor, 2004; Ishimura, Ichinose and Nomura, 2025). The removal of main effect variables due to collinearity limits the ability to make statements about the direct differences in trade volumes, restricting interpretation to relative changes captured by interactions. As highlighted in Magee (2008) and in subsequent applications of the gravity model (Anderson, Larch and Yotov, 2018; Martin and Pham, 2020), the inclusion of importer and year fixed effects captures the total imports of each country in each year. Similarly, exporter and year fixed effects capture the total exports of each country in each year. While this significantly improves model robustness by accounting for broad macro-level variations, it also means that the model cannot separately identify the effects of trade policy or agreements that influence specific bilateral flows. Particularly in distinguishing between intra-bloc (within a group, e.g., EU to OECD) and extra-bloc (outside the group) trade. In multiple models, the variables for EU membership, OECD membership, and post-2021 main effects are removed due to perfect collinearity with fixed effects. The removal of these variables does not compromise the estimation of interaction terms, which are identified from within-group and cross-country-year variations. This indicates that any increase in EU exports to OECD countries after the 2021 plastic waste ban that comes at the expense of EU exports to non-OECD countries may be partially "absorbed" by the exporter and year fixed effects. Similarly, overall changes in imports by OECD countries after 2021 are largely captured by the importer and year fixed effect. As a result, the triple interaction term $(EU_i \times OECD_j \times Post2021_t)$ primarily captures relative shifts in trade patterns across specific country-pairs, rather than absolute changes in total trade volumes. This limitation is analogous to the "trade creation vs. trade diversion" problem discussed in Magee (2008). While this study's specification allows for examining whether EU exporters shifted their plastic waste exports toward OECD countries after the 2021 ban, it does not fully disentangle whether this shift resulted from a reduction in exports to non-OECD partners, a general decline in total exports, or a combination of both. Consequently, the coefficient on the triple interaction should be interpreted cautiously as a relative effect, rather than a literal measure of absolute trade volume change. Thus, this limitation constrains interpretations of absolute trade differences, emphasizing that all policy insights must rely on relative changes captured by the interaction terms. Importantly, this limitation does not undermine the core insights of the analysis. The fixed effects still control for a broad set of confounding factors and ensure that the estimated effects of distance, GDP, and common language, as well as the post-2021 interaction with OECD membership. These are robust and not driven by unobserved macro shocks or country-level trends (Anderson, 2011; Head and Mayer, 2014).

Finally, I acknowledge that future research directions can complement the current approach. While the fixed effects and robustness checks provide credible control for many confounding factors, alternative identification strategies, such as synthetic control methods (Adarov, 2023) or less absorbing fixed effects, can be used to more precisely quantify trade diversion versus trade creation resulting from regulatory changes. Moreover, additional data collection on bilateral agreements or domestic regulatory enforcement would further strengthen inference.

# 8. Concluding Remarks

This study contributes to understanding the global trade of plastic waste, with a focus on how the 2021 EU restrictions on exports may have affected flows to non-OECD countries. By employing a gravity model with PPML estimation, the analysis accommodates zero trade flows and addresses heteroskedasticity, providing more reliable estimates of the associations between trade and its potential determinants.

The results indicate that geographic distance continues to act as a substantial barrier to plastic waste trade, reflecting the logistical and cost-related challenges associated with long-distance shipments. Economic size, captured by both exporter and importer GDP, shows variable relationships with trade flows, suggesting that larger markets do not uniformly drive increased exports or imports of plastic waste. Institutional factors, particularly EU membership, OECD membership of the importer, and the post-2021 period, appear to be associated with shifts in trade patterns, consistent with the hypothesized effects of the 2021 EU restrictions. However, these associations should be interpreted with caution, as the observational nature of the data limits the ability to define definitive causal claims.

Robustness checks further contextualize these findings. Alternative fixed effects specifications and a country-pair fixed effect model support the main results, while a comparison with aluminum trade indicates that plastic waste may respond differently to institutional and regulatory factors. While aluminum trade primarily reflects economic size and distance, plastic waste flows seem more sensitive to regulatory and governance-related characteristics. This further hights the commodity-specific nature of these dynamics.

In summary, the evidence presented here offers preliminary insights into how international regulatory measures, such as the EU's 2021 restrictions, may influence plastic waste flows to OECD countries. The study remains cautious in its interpretations, recognizing the limitations of available data and the complexity of global waste trade. These findings may inform policymakers and researchers interested in sustainable waste management and the broader implications of regulatory interventions, while underscoring the need for further research to disentangle the specific causal mechanisms at play.

# References


Adarov, A. (2023) “Eurasian economic integration: impact evaluation using the gravity model and the synthetic control methods,” *Review of World Economics*, 159(2), pp. 467–504. Available at: https://doi.org/10.1007/s10290-022-00473-2.

Anderson, J.E. (2011) “The Gravity Model,” *Annual Review of Economics*, 3(1), pp. 133–160. Available at: https://doi.org/10.1146/annurev-economics-111809-125114.

Anderson, J.E., Larch, M. and Yotov, Y.V. (2018) “GEPPML: General equilibrium analysis with PPML,” *The World Economy*, 41(10), pp. 2750–2782. Available at: https://doi.org/10.1111/twec.12664.

Anderson, J.E. and van Wincoop, E. (2003) “Gravity with Gravitas: A Solution to the Border Puzzle,” *The American Economic Association*, 93, p. 23. Available at: Anderson, J. E., & van Wincoop, E. (2003). Gravity with Gravitas: A Solution to the Border Puzzle. The American Economic Review, 93(1), 170–192. http://www.jstor.org/stable/3132167.

Anderson, J.E. and Yotov, Y.V. (2016) “Terms of trade and global efficiency effects of free trade agreements, 1990–2002,” *Journal of International Economics*, 99, pp. 279–298. Available at: https://doi.org/10.1016/j.jinteco.2015.10.006.

Baier, S.L. and Bergstrand, J.H. (2001) “The growth of world trade: tariffs, transport costs, and income similarity,” *Journal of International Economics*, 53(1), pp. 1–27. Available at: https://doi.org/10.1016/S0022-1996(00)00060-X.

Baier, S.L. and Bergstrand, J.H. (2007) “Do free trade agreements actually increase members’ international trade?,” *Journal of International Economics*, 71(1), pp. 72–95. Available at: https://doi.org/10.1016/j.jinteco.2006.02.005.

Borrelle, S.B. *et al.* (2020) “Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution,” *Science*, 369(6510), pp. 1515–1518. Available at: https://doi.org/10.1126/science.aba3656.

Burger, M., Van Oort, F. and Linders, G.-J. (2009) “On the Specification of the Gravity Model of Trade: Zeros, Excess Zeros and Zero-inflated Estimation,” *Spatial Economic Analysis*, 4(2), pp. 167–190. Available at: https://doi.org/10.1080/17421770902834327.

Carrère, C. (2006) “Revisiting the effects of regional trade agreements on trade flows with proper specification of the gravity model,” *European Economic Review*, 50(2), pp. 223–247. Available at: https://doi.org/10.1016/j.euroecorev.2004.06.001.

Copeland, B.R. and Taylor, M.S. (2004) “Trade, Growth, and the Environment,” *Journal of Economic Literature*, 42(1), pp. 7–71. Available at: https://doi.org/10.1257/.42.1.7.

Feenstra, R. and Kee, H.L. (2004) “On the Measurement of Product Variety in Trade,” *American Economic Review*, 94(2), pp. 145–149. Available at: https://doi.org/10.1257/0002828041301524.

Fernández-Val, I. and Weidner, M. (2016) "Individual and time effects in nonlinear panel models with large N , T," *Journal of Econometrics*, 192(1), pp. 291–312. Available at: https://doi.org/10.1016/j.jeconom.2015.12.014.

Frankel, A.J. and Romer, D. (1999) "Does Trade Cause Growth?," *The American Economic Review*, 89, p. 21. Available at: https://www.jstor.org/stable/117025.

Head, K. and Mayer, T. (2014) "Gravity Equations: Workhorse,Toolkit, and Cookbook," in *Handbook of International Economics*. Elsevier, pp. 131–195. Available at: https://doi.org/10.1016/B978-0-444-54314-1.00003-3.

Helpman, E., Melitz, M. and Rubinstein, Y. (2008) "Estimating Trade Flows: Trading Partners and Trading Volumes*," *Quarterly Journal of Economics*, 123(2), pp. 441–487. Available at: https://doi.org/10.1162/qjec.2008.123.2.441.

Herman, P.R. (2023) "Gravity Estimation: Best Practices and Useful Approaches," *2023-10-C*, p. 16.

Ishimura, Y., Ichinose, D. and Nomura, K. (2025) "Plastic waste trade and international agreements," *Environmental Economics and Policy Studies*, 27(3), pp. 357–376. Available at: https://doi.org/10.1007/s10018-024-00424-1.

Jiang, J. *et al.* (2022) "From plastic waste to wealth using chemical recycling: A review," *Journal of Environmental Chemical Engineering*, 10(1), p. 106867. Available at: https://doi.org/10.1016/j.jece.2021.106867.

Kellenberg, D. and Levinson, A. (2014) "Waste of Effort? International Environmental Agreements," *Journal of the Association of Environmental and Resource Economists*, 1(1/2), pp. 135–169. Available at: https://doi.org/10.1086/676037.

Li, J. and Takeuchi, K. (2023) "Import ban and clean air: estimating the effect of China's waste import ban on ozone pollution," *Environmental Economics and Policy Studies*, 25(4), pp. 471–492. Available at: https://doi.org/10.1007/s10018-023-00365-1.

Magee, C.S.P. (2008) "New measures of trade creation and trade diversion," *Journal of International Economics*, 75(2), pp. 349–362. Available at: https://doi.org/10.1016/j.jinteco.2008.03.006.

Martin, W. and Pham, C.S. (2020) "Estimating the gravity model when zero trade flows are frequent and economically determined," *Applied Economics*, 52(26), pp. 2766–2779. Available at: https://doi.org/10.1080/00036846.2019.1687838.

Nguyen, D.B. (2019) "A New Examination of the Impacts of Regional Trade Agreements on International Trade Patterns," *Journal of Economic Integration*, 34(2), pp. 236–279. Available at: https://doi.org/10.11130/jei.2019.34.2.236.

OECD (2021) *Trust in Global Co-operation: The vision for the OECD for the next decade*. Available at: https://www.oecd.org/en/about/legal/trust-in-global-cooperation-the-vision-for-the-oecd-for-the-next-decade.html.

OECD (no date) *Members and Partners*. Available at: https://www.oecd.org/en/about/members-partners.html.

"CEPII - GeoDist" (no date). Available at: https://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=6 (Accessed: May 29, 2025).

*EU countries | European Union* (no date). Available at: https://european-union.europa.eu/principles-countries-history/eu-countries_en (Accessed: May 29, 2025).

*Regulation - 2021/1840 - EN - EUR-Lex* (no date). Available at: https://eur-lex.europa.eu/eli/reg/2021/1840/oj/eng (Accessed: June 9, 2025).

Rose, A.K. (2000) "One money, one market: the effect of common currencies on trade," *Economic Policy*, 15(30), pp. 8–0. Available at: https://doi.org/10.1111/1468-0327.00056.

Silva, J.M.C.S. and Tenreyro, S. (2006) "The Log of Gravity," *The Review of Economics and Statistics*, 88(4), pp. 641–658. Available at: https://doi.org/10.1162/rest.88.4.641.

Tinbergen, J. (1963) "Shaping the world economy," *The International Executive*, 5(1), pp. 27–30. Available at: https://doi.org/10.1002/tie.5060050113.

*UN Comtrade* (no date). Available at: https://comtradeplus.un.org/TradeFlow?Frequency=A&Flows=X&CommodityCodes=TOTAL&Partners=251&Reporter (Accessed: May 29, 2025).

United Nations (2019) "Report of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal on the work of its fourteenth meeting," in. *Basel Convention*, Geneva: United Nations.

US EPA, O. (2023) *Impacts of Plastic Pollution*. Available at: https://www.epa.gov/plastics/impacts-plastic-pollution (Accessed: September 16, 2025).

Westerlund, J. and Wilhelmsson, F. (2011) "Estimating the gravity model without gravity using panel data," *Applied Economics*, 43(6), pp. 641–649. Available at: https://doi.org/10.1080/00036840802599784.

Wooldridge, J.M. (2010) *Econometric analysis of cross section and panel data*. 2nd ed. Cambridge, Mass: MIT Press.

*World Development Indicators | DataBank* (no date). Available at: https://databank.worldbank.org/source/world-development-indicators (Accessed: May 29, 2025).

# Popular science summary


Plastic waste is one of the biggest environmental challenges of our time. To tackle the growing problem of plastic pollution, the European Union (EU) introduced a ban in 2021 on exporting certain types of plastic waste to countries outside the OECD, a group of mostly high-income nations with stronger environmental regulations. But what happened to the EU's plastic waste trade after this policy? Did exports shift to other regions, or did the ban effectively reduce the flow of waste abroad? This study aimed to answer these questions using detailed trade data and advanced statistical methods.

Using a dataset covering bilateral trade flows of plastic waste from EU countries between 2017 and 2023, I employed a model that can account for the unique challenges of trade data, such as zero exports between some country pairs and large differences in trade volumes. The focus was on understanding whether the EU redirected plastic waste exports toward OECD countries after the ban, and whether non-OECD countries received more waste as a potential unintended consequence.

The results show that, in the short term, the policy did not lead to large-scale changes in trade patterns. There is no strong evidence that EU exports to OECD countries increased relative to exports to other regions, nor that non-OECD countries became new destinations for plastic waste. In other words, the ban seems to have largely prevented plastic waste from being sent abroad, without triggering major shifts to other countries.

It is important to interpret these results carefully. The post-ban period analyzed in this study is relatively short, and trade patterns may change over a longer time horizon. Additionally, data on niche waste commodities are sometimes incomplete, which can make detecting subtle trade adjustments challenging. Nevertheless, the study demonstrates that rigorous statistical methods can be used to monitor the effects of environmental policies on international trade, helping policymakers understand both intended and unintended consequences.

Overall, this research contributes to our understanding of how environmental regulation interacts with global trade. It suggests that targeted policy interventions, like the EU's 2021 plastic waste ban, can reduce harmful waste exports without immediately creating new environmental burdens elsewhere. While ongoing monitoring and further research are needed to fully assess long-term impacts, these findings provide cautious optimism that regulatory action can help address the global plastic waste problem.

# Appendix 1. List of countries in the dataset

AFGHANISTAN
ALBANIA
ALGERIA
ANDORRA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELIZE
BENIN
BHUTAN
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
COSTA RICA
CROATIA
CUBA
CYPRUS
DENMARK
DJIBOUTI
DOMINICA
ECUADOR
EL SALVADOR
EQUATORIAL GUINEA
ESTONIA
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUINEA
GUINEA-BISSAU
GUYANA
HAITI
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KENYA
KIRIBATI
KUWAIT
LATVIA
LEBANON
LESOTHO
LIBERIA
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALDIVES
MALI
MALTA
MAURITANIA
MAURITIUS
MEXICO
MONGOLIA
MOROCCO
MOZAMBIQUE
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
OMAN
PAKISTAN
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
ROMANIA
RWANDA
SAMOA
SAO TOME AND PRINCIPE
SAUDI ARABIA
SENEGAL
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVENIA
SOMALIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SURINAME
SWEDEN
SWITZERLAND
TAJIKISTAN
THAILAND
TOGO
TONGA
TRINIDAD AND TOBAGO
TUNISIA
TURKMENISTAN
TUVALU
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM
URUGUAY
UZBEKISTAN
VANUATU
ZAMBIA
ZIMBABWE

# Appendix 2. List of EU and OECD member states

| Group | Member countries |
| --- | --- |
| European Union (EU) | Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden |
| Organisation for Economic Co-operation and Development (OECD) | Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States |

*Source: EU countries | European Union (2025) and OECD (2025).*

# Appendix 3. List of regional groups included in Model (4)

| Regional Group | Countries |
|---|---|
| Africa | Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Chad, Comoros, Congo, Cote d'ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Togo, Uganda, Zambia, Zimbabwe |
| Asia | Armenia, Azerbaijan, Bahrain, Bangladesh, Bhutan, Cambodia, China, Georgia, India, Indonesia, Japan, Jordan, Malaysia, Maldives, Mongolia, Nepal, Oman, Pakistan, Philippines, , Singapore, Sri Lanka, Tajikistan, Thailand, Turkmenistan, Uzbekistan, Vietnam |
| Europe | Albania, Andorra, Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom |
| Middle East | Afghanistan, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Pakistan, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen |
| North and Central America | Canada, Mexico, United States, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Trinidad and Tobago, Jamaica, Belize |
| South America | Argentina, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Suriname, Uruguay, Guyana |
| Oceania | Australia, Fiji, Kiribati, New Zealand, Papua New Guinea, Samoa, Tonga, Vanuatu |

*Source: author's calculation*

# Appendix 5. Results of Country-pair FE

*Table 6. Results of PPML with biltareal and year Fixed Effects*

| Variable | Estimate |
|---|---|
| *log*(GDP exporter) | 1.209 |
| | (0.771) |
| *log*(GDP importer) | -2.846** |
| | (0.926) |
| EU*i* × Post 2021 | 0.229 |
| | (0.291) |
| OECD*j* × Post 2021 | 0.697*** |
| | (0.208) |
| EU*i* × OECD*j* × Post 2021 | -0.324 |
| | (0.323) |

*Note: Coefficients marked with *** p<0.01, ** p<0.05, * p<0.1. All standard errors are clustered at the exporter level and reported in parentheses. Fixed effects for biltateral country pairs and years, are included to account for unobserved heterogeneity*

# Appendix 6. Results as percentage changes

*Table 6. Results of Models 1-5 as percentage changes*

| Variable | Model (1) | Model (2) | Model (3) | Model (4) | Model (5) |
|---|---|---|---|---|---|
| Common language | +278% | +354% | +325% | +333% | +322% |
| *log*(Distance) | -68% | -64% | -69% | -65% | -71% |
| *log*(GDP exporter) | +100% | +186% | +109% | +101% | +161% |
| *log*(GDP importer) | +95% | +79% | -93% | +79% | -93% |
| EU*i* | +52% | - | +71% | -38% | - |
| OECD*j* | -57% | -79% | - | -80% | - |
| Post 2021 | -31% | - | - | - | - |
| EU*i* × Post 2021 | - | +17% | +41% | +27% | +21% |
| OECD*j* × Post 2021 | - | +131% | +119% | +151% | +102% |
| EU*i* × OECD*j* × Post 2021 | - | -27% | -41% | -34% | -29% |
| Observations | 20,085 | 20,085 | 20,085 | 19,540 | 20,085 |
| Exporter FE | No | Yes | No | No | Yes |
| Importer FE | No | No | Yes | No | Yes |
| Year FE | No | Yes | Yes | Yes | Yes |
| Regional dummies | No | No | No | Yes | No |

*Note: Coefficient estimations from Model 1-5 are reported as percentage changes. This is calculated by exponentiating each estimated coefficient, subtracting one, and multiplying by 100 (i.e., % change = [exp(β) − 1] × 100). For interaction terms, the percentage change represents the combined effect of all relevant coefficients, meaning the sum of the main effect and interaction coefficients is exponentiated before converting to a percentage. This allows for an intuitive interpretation of how a one-unit change in the explanatory variable (or combination of variables for interactions) impacts the expected trade flow, conditional on the fixed effects included in the model.*

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