The Effect of Economic Sanctions on World Trade of Mineral Commodities.

A Gravity Model Approach from 2009 to 2020.

Abstract

This article employs a gravity model to examine the impact of sanctions on the trade of mineral commodities, defined at a detailed level (i.e. six digits of the Harmonised System - HS), from 2009 to 2020. The dataset covers flows from 239 exporter countries to 38 OECD members. The primary findings highlight that: (i) a significant trade disruption is evident, characterized by an immediate 90 percent reduction, with a growing impact observed over time; (ii) sanctions-busting appears effective only in the very short term, albeit with weak supporting evidence; (iii) sender countries experience a decline in trade not only with target countries but also with third countries (negative network effect). An analysis by regions and HS chapters provides different evidence. North American sender countries exhibit the ability to replace imports from target countries with alternative suppliers, while EU countries experience a clear-cut trade disruption. When examining different HS chapters, findings indicate that sanctions lead to a reduction in trade of mineral commodities classified under chapters 26 and 27, but not in those under chapter 25. Regarding sanctions-busting, it appears evident for commodities under Chapter 26. However, sender countries importing commodities under Chapter 25 seem to be able to shift to other sources, whereas sender countries importing commodities under Chapter 27 experience a substantial trade disruption.

Keywords: Trade Sanctions; Mineral commodities; Industrial raw materials; Gravity Model; Trade disruption; Trade diversion; Sanctions - Busting.

JEL Codes: F100, F130, F140, F500, F510, N400, N500.

1 Introduction

This article aims to assess the impact of trade sanctions on world trade of industrial raw materials within the mineral sector, defined at a detailed level (i.e. six digits of the Harmonised System - HS), utilizing a dataset covering flows from 239 exporter countries to 38 OECD members, during the period 2009-2020.

Sanctions, as defined by Morgan et al. (2023), are "restrictive policy measures" taken by one or more countries to limit their relations with a target country to persuade that country to change its policies or address potential violations of norms and international conventions. Negative sanctions encompass punitive actions implemented by a sending state to inflict economic harm on a target state. In many cases, they serve as an alternative foreign policy tool to the use of military force.

From an economic perspective, economic sanctions disrupt extant economic interactions or impede the establishment of new ones. Specifically, trade sanctions can take various forms to restrict or prohibit trade, such as embargoes, import or export bans, or other trade barriers. By design, trade sanctions diminish the volume of trade between the sender and the target. Nevertheless, sanctions do not determine trade disruption only but their impact extends to third countries as well.

Van Bergeijk (1994a,b, 1995) elucidates the emergence of sanctions-busting and negative network effects as consequential outcomes of sanctions. They might determine trade diversion through mechanisms aimed at circumventing sanctions (namely sanctions-busting). In such cases, sanctions give rise to trade patterns between target countries and third countries that are not implicated in the sanctioning framework. Nevertheless, sender countries may also seek to augment trade volumes with third parties as a means of replacing the target countries in their trade partnerships. For example, when the U.S. imposed a comprehensive embargo on Nicaragua, European nations continued to maintain trade relations, and Canada even facilitated Nicaragua's relocation of its foreign trade office from Miami to Toronto in an attempt to facilitate circumvention of the sanctions. The insightful work by Early (2015) provides an in-depth examination of sanctions-busting. In summary, the evidence surrounding sanctions-busting is somewhat intricate, as a substantial number of states engage in trade-based sanctions evasion.

Critical factors to evaluate the likelihood of sanctions-busting are whether the sanctions are 1) partial or comprehensive; and 2) unilateral or multilateral. Unilateral and partial sanctions hold limited effectiveness, as sanctions-busting readily occurs, thereby hindering the effective isolation of the target country. Partial yet multilateral sanctions may prove more effective provided there is effective coordination within the international community.

In scenarios involving total but unilateral sanctions, both negative network effects and the phenomenon of sanctions-busting become apparent. It is evident that in the presence of multilateral sanctions, the emergence of sanctions-busting is less likely.

As noted above, trade diversion represents just one facet of altered trade patterns. In reality, sanctions can be so far-reaching that they lead to generalized trade disruption, a phenomenon referred to as negative network effects. In empirical terms, negative network effects result in a decrease in trade flows not only between sender and target countries but also involving third countries. Moreover, they lead to a decrease in imports from both the target country and alternative sources.

The focus on mineral commodities is motivated by several compelling factors. Firstly, the surge in economic growth and industrialization has led to a heightened demand for minerals in the long run. Stuermer (2017) exploits a dataset including a sample of 12 industrialized countries and three recent fast-industrializing countries (China, India, Brazil) from 1840 to 2010 to investigate the long-run demand for mineral commodities. The impact of GDP per capita on long-run demand for minerals is clear-cut albeit heterogeneous concerning specific commodities. Additionally, as investigated in Islam et al. (2022) the transition towards clean energy sources has further augmented this demand, necessitating substantial quantities of minerals as essential raw materials. Renewable energy technologies require more raw minerals than traditional technologies. In particular, OECD countries have increased the demand for minerals. In some cases, demand also violates the traditional Marshallian demand because imports do not decrease in the face of a higher mineral price. Secondly, as explained in Moroney and Trapani (1981) the potential for substitution for mineral-intensive industries is constrained, and therefore in the case of sanctions this could constitute a significant impact on the global trade.

The focus on the mineral sector aligns our article closely with Larch et al. (2022); which underscores a significant reduction of about 44 percent in mining trade between sanctioned and sanctioning countries due to sanctions. However, unlike the aforementioned research, we aim to provide a more comprehensive analysis of the impact of sanctions by disaggregating mineral trade down to the HS 6-digit level. To achieve this, we define a dummy variable that combines the presence of complete sanctions between importer and exporter with any trade restrictions on specific mineral commodities.

We integrate data from the OECD Inventory of export restrictions on industrial raw materials and the Global Sanctions Database (GSDB), created by Felbermayr et al. (2020a) (https://www.globalsanctionsdatabase.com/). Our study is based on imports of 63 raw mineral commodities (HS Section V) from 239 exporters to 38 OECD countries spanning the period from 2009 to 2020. By employing such detailed data, we seek to contribute to the existing literature, as the utilization of disaggregated data to explore the trade effects of sanctions has been notably limited, primarily due to data scarcity.

With respect to existing literature quantifying the impact of economic sanctions on international trade in the mining sector (Larch et al., 2022), our article contributes by assessing both the direct and indirect effects of trade sanctions. Direct effects, such as trade disruption and the effectiveness of sanctions-busting, are analyzed to understand their immediate impact on sender-target trade relationships. Additionally, the article considers the indirect effect of trade diversion, exploring how sanctions affect trade patterns with third countries, and providing a deeper understanding of the implications of trade sanctions for global trade networks.

To do that we employ a gravity model, which represents the prevailing empirical approach for scrutinizing international trade patterns. This model, initially introduced by Isard (1954) and further developed by Tinbergen (1962) and Linnemann (1966), explicates trade interactions between two countries by incorporating factors such as their economic scale, geographical proximity, and other pertinent variables. We augment the traditional gravity model with three dummy variables to capture: (i) the degree of trade disruption between sender and target countries; (ii) whether a sender country redirects its imports from a target country to an alternative supplier country; (iii) whether the target country diverts its exports to third countries. Both (ii) and (iii) would constitute trade diversion or sanctions-busting, albeit involving different countries.

As predicted, the baseline empirical findings show the immediate trade disruption occurring between the sender and target countries. Notably, when considering different time lags, our analysis reveals an interesting trend in the coefficient, indicating a growing impact over time. Specifically, it rises from an immediate 90 percent effect to 95 percent after four years, eventually decreasing to a 66 percent impact after five years. More intriguingly, between one and up to four years following the imposition of the sanction, there is a decrease in trade not only between the countries directly affected by the sanction but also with third countries. To be specific, a trade sanction leads to a reduction in trade for the sender countries, ranging from approximately 27 percent after one year to approximately 46 percent after four years. Furthermore, we conducted a reiteration of the analysis, specifically highlighting the impact of sanctions on distinct minerals. It is noteworthy that when scrutinizing the data according to mineral types, both trade disruption and trade diversion manifest quantitatively distinct outcomes.

Our work has two limitations. The first is that our model does not account for trade effects stemming from the substitution of domestic sales. Addressing this would necessitate a model with a nested CES structure and access to domestic trade data at a level of disaggregation equivalent to that of international trade (Heid et al., 2021). Despite our endeavors to evaluate the influence of trade sanctions using meticulously detailed data, trade policies exhibit substantial divergence across products and countries, and comprehensive data about intra-national trade are unavailable. A second limitation arises from the dummy variable we have constructed to identify the presence of a sanction. Because certain bans or prohibitions may not necessarily originate from a sanction, our variable could inadvertently incorporate the negative impact of other types of bans, thus potentially slightly overestimating the impact of sanctions.

However, given that we have exclusively focused on comprehensive sanctions, the likelihood of our variable accurately identifying the presence of a sanction on a particular commodity is high.

The article is structured as follows: Section 2 provides the literature review; Section 3 describes the empirical strategy for estimating the impact of trade sanctions on minerals; Section 4 elucidates our approach to merging the two databases and creating a bilateral dummy variable to indicate the presence of trade sanctions at the product level, and provides some descriptive statistics, Section 5 presents and discusses the results and finally, Section 6 concludes.

2 Literature review

This work contributes to the sparse literature on the economic impact of sanctions. The economic impact is crucial to predict the political success of such punitive measures (see among others Bapat et al. (2013); Bonetti (1998); Pape (1997); Hufbauer et al. (1990)). In general, when delving into the economic consequences, trade sanctions have a negative impact on bilateral trade flows between the target countries and their trading partners (Felbermayr et al., 2020a,b).

In a previous study by Caruso (2003), a gravity equation is used to examine the impact of U.S.

sanctions imposed during the period from 1960 to 2000. The analysis extends beyond the U.S. and the target countries, including trade flows with other G-7 nations. It is found that if the U.S. refrained from implementing unilateral negative sanctions during the present period, its trade with target countries could be approximately 60 percent higher, with even greater losses in the case of global sanctions, exceeding 80 percent. Interestingly, the absence of U.S. sanctions would lead to a 17 percent reduction in trade for other G-7 nations, indicating that U.S. sanctions inadvertently boost the exports of these countries. This highlights the need to consider these factors when evaluating the effectiveness of negative sanctions. However, it is important to note that negative network effects still occur with total sanctions, especially as the number of trade ties of the target country increases, potentially leading to sanctions-busting during the present period. Afesorgbor (2019) delves into the distinct impact of economic sanctions when they are threatened versus when they are imposed on international trade flows. The findings reveal qualitative and quantitative differences in the effects of threatened and imposed sanctions. Specifically, while imposed sanctions result in a reduction in trade flows between the sender and the target country, the mere threat of sanctions tends to have the opposite effect, leading to an increase in trade.

A study by Larch et al. (2022) uses a gravity equation to analyze the impact of sanctions on bilateral trade in the mining industry, including oil and natural gas. The study finds that sanctions have effectively hindered mining trade, with complete trade sanctions reducing bilateral mining trade by an average of 44 percent. Mining commodities play a significant role in global trade, accounting for 20 percent of world trade, and are crucial for the economic growth of nations. Therefore, sanctions in the mining sector can significantly undermine economic activity and well-being, particularly in the sanctioned states. Doan and Tran (2023) conducted an empirical examination into the impact of economic sanctions on the exchange of cultural commodities, utilizing cross-country data encompassing 5,304 country pairs over the period spanning from 1996 to 2019. The primary empirical outcomes reveal that economic sanctions exert a stimulative effect on the trade of cultural goods. This impact exhibits heterogeneity across diverse categories of economic sanctions. Notably, military, arms, trade, and travel sanctions are observed to function as facilitators of cultural goods trade, while financial and other sanctions act as impediments. Furthermore, these effects are contingent upon the economic development level of the target countries and exhibit temporal dynamics.

Golub (2020) analyses the emergence of sanctions-busting for sanctions imposed between 1950 and 2006. Contrary to prevailing literature, the empirical results indicate that the occurrence of sanctions busting from 1950 to 2006 does not stem from the intervention of allies on behalf of the target, nor does it result from companies gravitating toward highly dependent third-party states or democratic trade partners of democratic targets. Moreover, there is no observable shift away from states involved in military disputes with the target.

Other works focus on specific case studies. Nguyen and Do (2021) examine the impact of economic sanctions imposed on the exports of the Russian Federation and the effect of Russian counter-sanctions. The authors use the data from 49 trading partners of Russia from 2011 to 2018 and employ a gravity modelling approach. The study reveals that (i) economic sanctions imposed on the Russian Federation and the corresponding counter-sanctions result in notable contractions in both the overall export and Russian import values. Specifically, the sanctions induce a decline of 25.25 percent in the Russian export values, while counter-sanctions lead to a 25.92 percent reduction in the Russian import values from the originating countries; (ii) the impacts of sanctions and counter-sanctions vary across export and import product categories. Notably, the sanctions significantly impact the Russian export of oil products, causing a substantial 36.56 percent reduction in export value, whereas the effects of the sanctions on the Russian export of non-oil products are deemed insignificant. More recently, a study by Miromanova (2023) analyzed the effects of the retaliatory import embargo imposed in 2014 by Russia in response to sanctions imposed by a coalition of Western countries. Using data on firm-level trade, the study focused on the extensive margin (likelihood of importing a product from a specific country over time) and the intensive margin (value of import transactions), revealing statistically significant negative impacts of the embargo on both margins.

Evenett (2002) assessed the impact of sanctions on South Africa by gauging the influence of eight developed economies' sanctions on their imports from South Africa. Notably, the presence of outliers significantly impacts the parameter estimates. Disregarding these outliers may lead to the incorrect inference that sanctions imposed by the European countries had the most detrimental impact on South African exports. However, robustness checks underscore that the Comprehensive Anti-Apartheid Act enacted by the United States played the most substantial role, resulting in a one-third reduction in bilateral imports.

Other studies highlight the varied economic consequences of sanctions, including impacts on GDP growth, inequality, and unemployment. Neuenkirch and Neumeier (2015) assessed the impact of UN and US sanctions using a dataset comprising 160 countries, 67 of which were subjected to economic sanctions between 1976 and 2012. The results underscore that, on average, the implementation of UN sanctions leads to a reduction of over 2 percentage points in the target state's annual real per capita GDP growth rate. These adverse effects endure for a decade, resulting in an overall decline of 25.5 percent in the target country's GDP per capita. Specifically, comprehensive UN economic sanctions, encompassing embargoes affecting nearly all economic activities, determine a reduction in GDP growth by more than 5 percentage points. In contrast, the impact of US sanctions is notably smaller and less pronounced. The imposition of US sanctions diminishes the target state's GDP growth by 0.75–1 percentage point. This detrimental effect on growth persists for seven years, contributing to an aggregate decline in GDP of 13.4 percent. In a complementary study, Neuenkirch and Neumeier (2016) analyzed the repercussions of US economic sanctions on the poverty gap in target countries over the period from 1982 to 2011. The findings unveil an adverse impact of US sanctions on individuals in poverty, manifested by a 3.8 percentage point larger poverty gap in target countries compared to a control group meticulously matched in terms of observable pretreatment characteristics. Furthermore, the impact of sanctions on poverty exhibits the following characteristics: (i) a positive correlation with the severity of sanctions, (ii) a more pronounced effect for multilateral sanctions compared to unilateral sanctions imposed solely by the United States, and (iii) a persistent nature, with the poverty gap expanding over the initial 21 years of a sanction regime. Gharehgozli (2017) estimates that sanctions reduced Iran's real GDP by more than 17 percent in the period 2011-2014. Du and Wang (2022) use a multi-country multi-sector general equilibrium model with trade, multinational production (MP), and input–output linkages. The authors calibrate the model with 44 economies and 34 sectors before the Russia–Ukraine war in 2022. The counterfactual analysis suggests that the economic sanctions that cut trade between Russia and all other economies except China would decrease the real income in Russia by 11.98 percent. Moreover, if only trade linkages are cut, the real income in Russia would decrease by 9.55 percent. Kim et al. (2023) investigate the economic costs of the UN sanctions on North Korea by exploiting a data set on North Korean firms. Findings reveal that trade sanctions reduced the country's manufacturing output by 12.9 percent and real income by 15.3 percent. Kelishomi and Nisticò (2022) investigate the short-run effect of economic sanctions on manufacturing employment in Iran in 2012. Sanctions resulted in a comprehensive decrease in the growth rate of manufacturing employment by 16.4 percentage points.

Moeeni (2021) assesses the impact of economic sanctions on children's education, leveraging the United Nations sanctions imposed on Iran in 2006 as a natural experiment. Employing a methodological approach that leverages the variation in the strength of sanctions across industries and utilizing difference-in-differences with synthetic control analyses, the findings of this research indicate that the sanctions resulted in a decrease in children's total years of schooling by 0.1 years and a reduction in the probability of attending college by 4.8 percentage points. Additionally, households experienced a substantial 58 percent decrease in education spending, with a particular emphasis on reductions in school tuition expenditures.

Jeong (2020) examines the relationship between economic sanctions and income inequality of target states. Sanctions exhibit a noticeable impact on the income inequality of the target states. The contention is that this impact varies significantly depending on the specific sanctions employed and the economic circumstances of the targeted countries. Analyzing data from 152 countries spanning the period 1974 to 2011, the findings indicate that import sanctions contribute to an increase in inequality in labor-abundant target countries. However, this effect is not observed in labor-scarce target countries. Using a cross-country analysis of 68 target states from 1960 to 2008, Afesorgbor and Mahadevan (2016) find robust empirical evidence that the imposition of sanctions has a deleterious effect on income inequality.

3 Estimating the impact of trade sanctions on mineral commodities.

In this work, we assess the impact of sanctions on mineral commodities using a gravity model. Gravity models are widely used in international trade literature, and they are an application of Newton's law of gravity. The first applications of the gravity model in international trade literature were developed by Tinbergen (1962) and Pöyhönen (1963).

In this work, we assume that country i (the sender country) applies sanctions to mineral commodity k from target country j. If, after the sanctions, country i imports less of mineral commodity k from country j and more from country z, trade diversion has occurred. In contrast, if country i imports less of mineral commodity k from both j and z, trade destruction has occurred due to negative network effects (Van Bergeijk, 1995), such as changes in the world economic system (e.g., supply chain disruption) that influence the economic opportunities of countries not directly involved in the conflict.

Our gravity equation specification follows the methodology proposed by Yotov et al. (2016) and includes the following features:

1. exporter-sector-time and importer-sector-time fixed effects to account for unobservable multilateral resistance terms;

2. country-pair-sector fixed effects to consider time-invariant bilateral trade costs and mitigate endogeneity issues;

3. utilization of the Poisson Pseudo Maximum Likelihood (PPML) estimator to address heteroskedasticity in trade data and capture information within zero trade flows;

4. estimations are conducted using a dataset comprising consecutive-year data (Egger et al., 2022);

5. to address potential simultaneity problems, the dummy variables for the presence of trade sanctions are lagged by one year.

Letting $Sanction^k_{ij,t}$ denote the presence of a sanction between i and j on commodity k, we construct three dummy variables as follows:
- $Sanction^k_{ij,t}$ equal to 1 if there is a sanction applied by the sender country i on commodity k from target country j at time t and 0 otherwise. It is intended to capture the effect of sanctions on trade flows between sender and target countries;
- $Sender^k_{i,z\neq j,t}$ equal to 1 if there is a sanction applied by sender country i on commodity k but not from z at time t and 0 otherwise. It is intended to capture the potential trade diversion of the sender. Specifically, it aims to determine whether the sender replaces imports from the target country with imports from an alternative source.
- $Target^k_{c\neq i,j,t}$ equal to 1 if there is a sanction imposed to target country j on commodity k but not from c at time t and 0 otherwise. It is intended to capture whether the target country diverts its exports to third countries. In practice, it also captures the emergence of sanctions-busting.
Then we estimate the augmented gravity equation in multiplicative form using a Poisson pseudo-maximum-likelihood (PPML) estimator, commonly adopted in the recent empirical analyses (Silva and Tenreyro, 2006; Yotov et al., 2016):

$$X^k_{i,j,t} = exp[\alpha + \beta Gravity + \chi Sanction^k_{i,j,t-1} + \gamma Sender^k_{i,z\neq j,t-1} + \delta Target^k_{c\neq i,j,t-1} + \psi^k_{ij} + \phi^k_{it} + \theta^k_{jt}] \times \epsilon^k_{ij,t} \tag{1}$$

Our gravity equation (1) allows an assessment of the trade disruption or diversion of a trade sanction: - negative estimates of χ, γ, and δ are suggestive of a trade disruption; - positive estimates of γ and/or δ and a negative coefficient of χ suggest a trade diversion.

The *Gravity* controls included in the model are the following:

- the geodesic weighted distance between country i and country j, $Distance_{ij}$;

- the origin and destination nominal per capita GDP, in US dollars, respectively, $GDP_{i,t}$ and $GDP_{j,t}$;

- the dummy $Contiguity_{ij}$ equal to 1 if i and j share a land border;

- the dummy $Language_{ij}$ equal to 1 if i and j share the same official language;

- and finally, the dummy $Colony_{ij}$ equal to 1 if i and j are linked by colonial ties.

We inflate our specification including a set of dummies for country-pair-sector fixed effects, δ_{ij}^k, importer-time-sector fixed effects, ϕ_{it}^k, and exporter-time-sector fixed effects, θ_{jt}^k to control for unobservable and/or imperfectly measured variables and recover the multilateral resistance terms (Head and Mayer, 2014; Fally, 2015; Campos et al., 2021).

3.1 Data and descriptive statistics

Our data set is built around information covering imports of 63 raw mineral commodities (HS Section V) from 239 exporters to 38 OECD countries over the period 2009–2020. Appendix A provides a synthetic description of raw mineral commodities included in our empirical analysis. Data on trade at the HS6 level of detail, based on the WTO definition, are from the COMTRADE database [1], which are integrated into the WITS software [2], while data for the gravity variables are from the Cepii dataset[3].

Data on sanctions are from the OECD Inventory of Export Restrictions on industrial raw materials and the Global Sanctions Database (GSDB). The OECD database contains information on export regulations in the raw materials sector, namely minerals, metals, and wood, and records measures known to restrain export activity from 2009-2021 at the 6-digit level of HS-2007 classification. The updated GSDB (2021) covers 1,101 publicly traceable, multilateral, plurilateral, and purely bilateral sanction cases over the 1950-2019 time period.

The advantage of using the first database lies in its disaggregated product-level information. On the other hand, the second database, despite aggregating data by countries, offers insights into bilateral sanctions.

[1] https://comtrade.un.org/. Accessed on 5 October 2022.
[2] http://wits.worldbank.org/witsweb/default.aspx. Accessed on 5 October 2022.
[3] http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=8. Accessed on 5 October 2022.

We combine these two datasets by defining the dummy variable *Sanction* as 1 when the GSDB records a trade sanction imposed by an OECD country i on country j in year t, and when the OECD database registers an export prohibition or quota on good k from country j during the same year. Therefore, when we identify the presence of a trade sanction in both the bilaterally aggregated product-level database (GSDB) and the unilaterally disaggregated product-level database (OECD), we assign a dummy variable to the country-pair-product-year combination to indicate the presence of the sanction. Indeed, trade restrictions can stem from a variety of policies, making it challenging to rule out the possibility that a particular restriction or ban might be influenced by factors other than sanctions, such as VERs driven by different motives. Nevertheless, to enhance the reliability of our variable, we assigned the value of 1 only when the target country experienced a comprehensive punitive measure. In such cases, the likelihood that the restriction is linked to the sanctions imposed by the sending or importing country is notably higher. Nonetheless, we cannot entirely dismiss scenarios where this assumption does not hold true. Empirically, this could result in a slight overestimation of the impact of sanctions, albeit without compromising the overall validity of the findings. Table 1 provides a summary of how our variable of interest, namely $Sanction^k_{i,j,t}$, is constructed. Meanwhile, Table 2 provides descriptive statistics of the main variables in our dataset used in the empirical analysis.

Table 1: Variable $Sanction^k_{i,j,t}$

	GSDB	OECD
$Sanction^k_{ij,t} = 1$ when	$TradeSanction_{ij,t} = 1$ and	$ExportRestriction^k_{j,t} = 1$
$Sanction^k_{ij,t} = 0$ when	$TradeSanction_{ij,t} = 1$ and	$ExportRestriction^k_{j,t} = 0$
$Sanction^k_{ij,t} = 0$ when	$TradeSanction_{ij,t} = 0$ and	$ExportRestriction^k_{j,t} = 1$
$Sanction^k_{ij,t} = 0$ when	$TradeSanction_{ij,t} = 0$ and	$ExportRestriction^k_{j,t} = 0$
$Sanction^k_{ij,t} = 1$ when	$TradeSanction_{ij,t} = 1$ when if exp compl, imp compl	and any case
$Sanction^k_{ij,t} = 1$ when	$TradeSanction_{ij,t} = 1$ if exp part, imp compl	and any case

Notes: exp compl= complete export sanctions; imp compl= complete import sanctions; exp part= partial export sanctions; imp part= partial import sanctions;

Table 2: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	N. of Obs.
$Trade^k_{ij,t}$	655	41,783	0	18.6Ml	2,688,207
$Sanction^k_{ij,t}$	0.003	0.06	0	1	2,688,207
$Sender^k_{i,z\neq j,t}$	0.29	0.45	0	1	2,688,207
$Target^k_{c\neq i,j,t}$	0.02	0.15	0	1	2,688,207
$ln(Distance_{ij})$	8.45	1.03	2.48	9.88	2,688,207
$ln(GDP_{i,t})$	19.83	1.55	16.37	23.79	2,688,207
$ln(GDP_{j,t})$	18.60	2.01	10.21	23.79	2,688,207
$Contiguity_{ij}$	0.029	0.17	0	1	2,688,207
$Language_{ij}$	0.09	0.28	0	1	2,688,207
$Colony_{ij}$	0.01	0.11	0	1	2,688,207

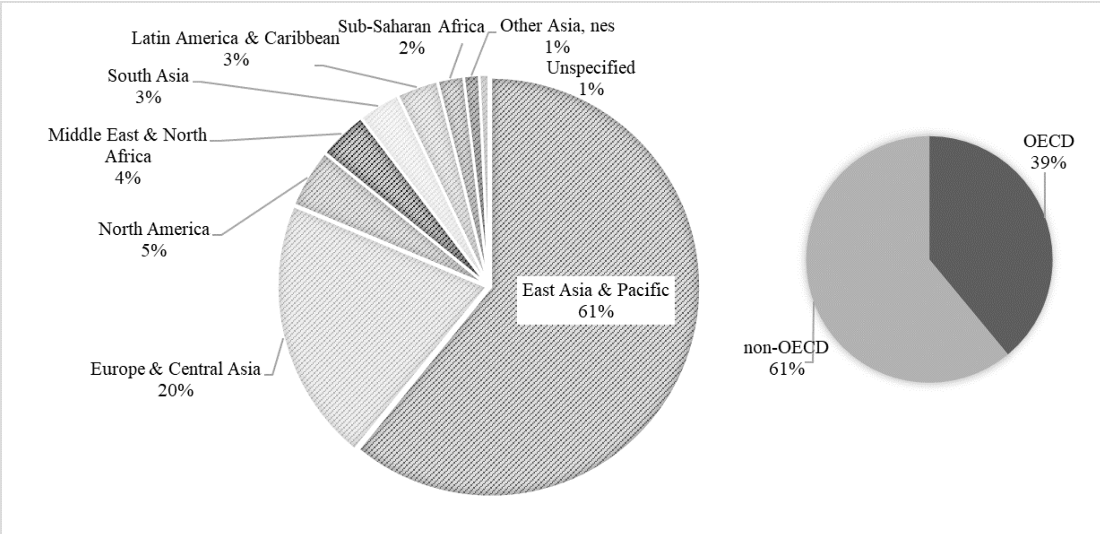
4 Facts in mineral trade

Figure 1 shows the share of the world's mineral imports across various regions. Notably, East Asia and the Pacific region are the largest importers of mineral commodities (accounting for 61 percent of world trade in minerals), mainly driven by China's imports. However, our dataset does not include China as an importer since it is not an OECD member. However, China does not impose trade sanctions on its mineral trading partners. It is worth noting that China, included in the dataset as an exporter, has a *Sanction* dummy equal to 1 during the 2017-2020 period due to sanctions imposed by US.

In contrast, countries in Europe and Central Asia import 20 percent of mineral commodities, while North America's share stands at 5 percent. The OECD members included in our dataset account for approximately 40 percent of the world's mineral imports in the period 2009- 2020. Exporters are targeted differently by importers.

The dummy variable *Sanction* is equal to 1 for sanctions imposed by countries in Europe and Central Asia on commodities from Myanmar, Armenia, the Russian Federation, Ukraine, Egypt, the Arab Republic, Israel, Saudi Arabia, Guinea, and Zimbabwe. In the case of North America, the *Sanction* dummy is 1 for raw materials from China, as well as minerals from Indonesia, Korea, Democratic Republic, Myanmar, Vietnam, Kyrgyz Republic, Russian Federation, Turkey, Ukraine, Bolivia, Colombia, Cuba, Jamaica, Iran, Islamic Republic, Saudi Arabia, Congo, Democratic Republic, Former Sudan, Ghana, Nigeria, Sierra Leone, and South Africa. Lastly, countries in the East Asia and Pacific region, during the period under analysis, imposed sanctions on Indonesia, Korea, Democratic Republic, Russian Federation, and Ukraine.

Figure 1: Imports of Mineral Commodities: Share by regions (2009–2020)



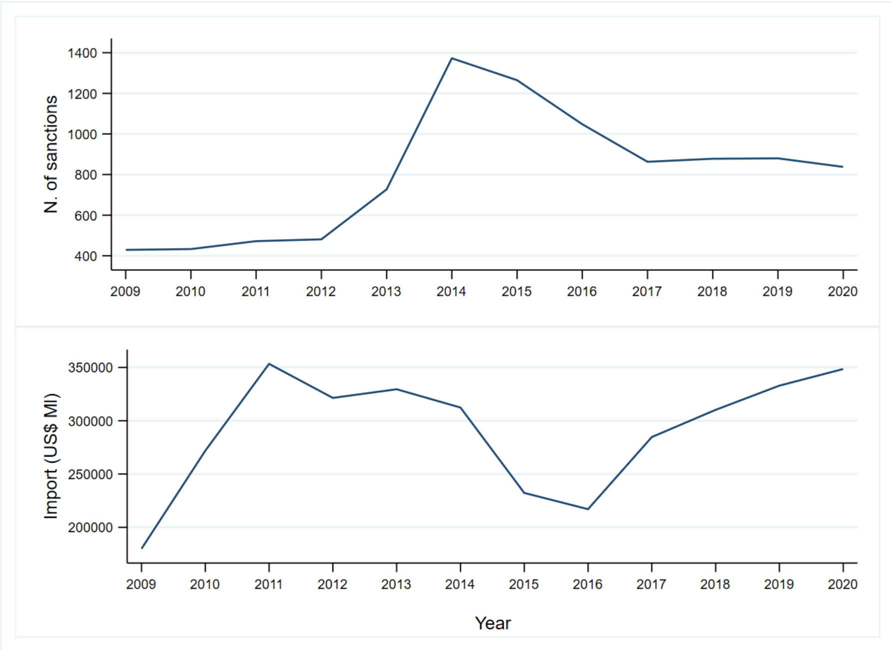
Note: Elaborations on WITS (https://wits.worldbank.org/); Simple average over period 2009-2020.

Figure 2 depicts the trends in the number of sanctions and imports from 2009 to 2020. The figure reveals a striking correlation, emphasizing the significant impact of trade sanctions on mineral imports. It is evident that when the number of sanctions increases, there is a corresponding decrease in imports. Conversely, during periods when the number of sanctions decreases, imports increase.

The peak of sanctions in the year 2014 is due to the sanctions imposed on Russia and Ukraine. Conversely, the noticeable reduction in recent years descends from the lifting of sanctions against Iran.

When we examine the number of sanctions imposed by various sender countries and enforced on different targets (Figure 3), a clear hierarchy emerges. The United States, the United Kingdom, and Canada are the major sender countries, often imposing sanctions on different states, followed by EU members. On the other side, the main targets of these sanctions are Russia, Zimbabwe, Egypt, Myanmar, and Iran.

Figure 2: Trends in Sanctions and Imports (2009-2020)

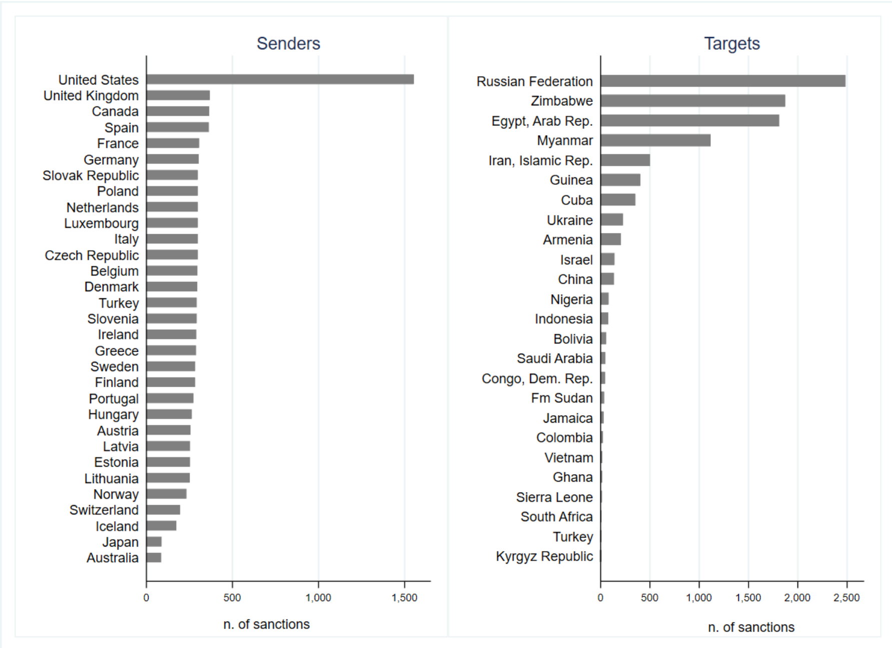


Note: Elaborations on GSDB (https://globalsanctionsdatabase.com/), OECD (https://data.oecd.org/) and WITS (https://wits.worldbank.org/).

Turning our attention to the trade of minerals, we observe a notable contrast between countries that are major mineral exporters and those that are major importers. The top OECD importer countries are Japan and South Korea. Remarkably they impose relatively few sanctions on mineral commodities. In contrast, the major sender countries, including those in North America, the UK, and EU member states, have lower levels of mineral imports (see Figure 4).

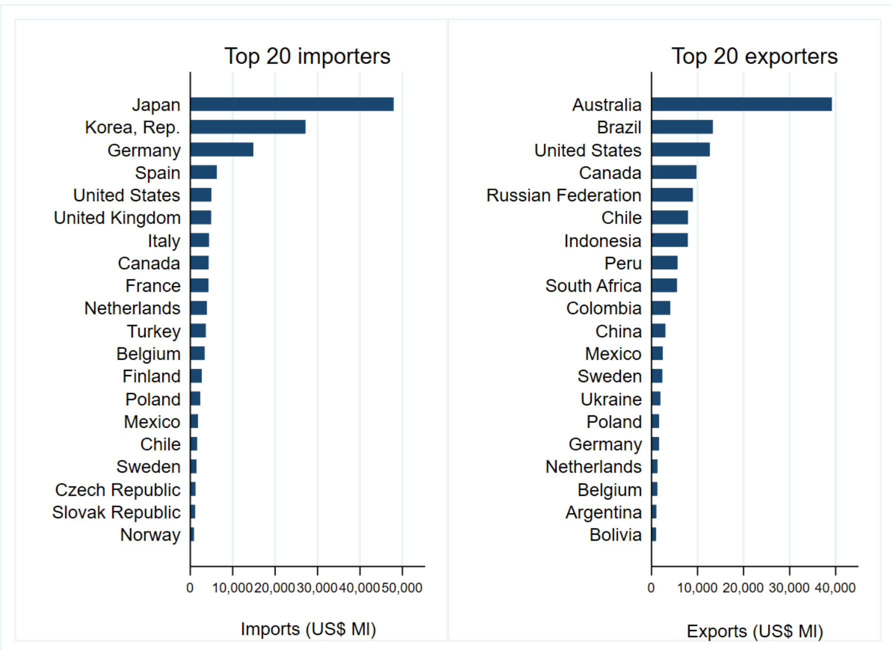
It is interesting to note Russia, despite being heavily affected by trade sanctions, remains among the top five mineral exporters whereas the other major exporters such as Australia, Brazil, the US, and Canada are not affected by trade sanctions.

Figure 3: Number of sanctions by senders and targets (2009–2020)



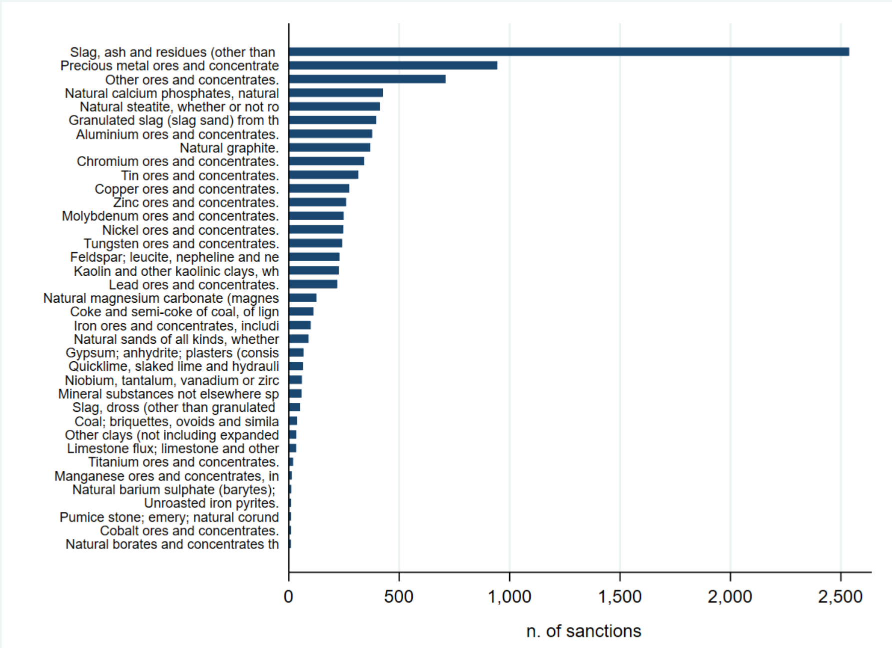
Note: Elaborations on GSDB (https://globalsanctionsdatabase.com/), OECD (https://data.oecd.org/).

Figure 4: The Top 20 Importers and Exporters of Minerals (2009–2020).



Note: Elaborations on WITS (https://wits.worldbank.org/).

Figure 5: Sanctioned product (HS4) (2009–2020).



Note: Elaborations on GSDB (https://globalsanctionsdatabase.com/), OECD (https://data.oecd.org/).

Focusing on the mineral commodities most commonly subject to trade sanctions (Figure 5), we can observe that these sanctions encompass a wide array of resources, spanning from precious metals to industrial minerals and ores. The targeted materials encompass slag, precious metal ores, non-ferrous metal ores, calcium phosphates, steatite, granulated slag, aluminum ores, natural graphite, chromium ores, and tin ores.

In particular, sanctions on slag, ash, residues, precious metal ores, and concentrates, as well as other ores and concentrates, have significant implications for various countries, with the primary targets being Russia, Ukraine, Myanmar, Egypt, Guinea, and Zimbabwe.

Other commodities, such as aluminum ores and concentrates, exhibit a diverse range of destination countries. The list of target countries encompasses China, Cuba, Egypt, the Arab Republic, Guinea, Indonesia, Iran, the Islamic Republic, and Myanmar. Overall, the wide spectrum of sanction targets, both countries and products, reflects the global reach and demand within the mineral sector.

In these materials, sanctions may play a crucial role across various sectors, and trade restrictions concerning them can result in supply chain disruptions, affecting market prices, and generating economic and political consequences for both importing and exporting nations.

5 Econometric results

As the rich structure of fixed effects fully accounts for the multilateral resistance terms (Head and Mayer, 2014; Fally, 2015), we rely on the gravity framework that employs the strategy of fixed effects and consider the results in Table 3 as our baseline results. Therefore, we estimate equation (1) with the full structure of fixed effects, including importer-product-time fixed effects, exporter-product-time fixed effects, and country-pair-product fixed effects[4]. These fixed effects also encompass all aspects of the gravity variables employed in the literature, enabling us to control for unobserved characteristics.

Our main results remain robust with the inclusion of gravity variables instead of the set of fixed effects. Additionally, in order to check the robustness of our variable of interest, we estimate the trade impact of sanctions using aggregated data and the trade sanction variable from the GSDB. Consistently, the results demonstrate a negative and statistically significant impact (see Appendix B for detailed results).

Column (1) in Table 3 shows the results for the full sample without any lags applied to the interest variables related to the trade sanction. In the other columns, we introduce a one-year lag (Column (2) and continue this pattern until the five-year lag (Column (5)) is incorporated. The use of lagged values of the $Sanction^{k}_{ij,t}$ relies on the intuitive argument that dependent and independent variables cannot fully adjust within 1 year (Cheng and Wall, 2005).

Across all specifications, as indicated in Table 3, we find consistent evidence of the trade sanction, denoted as $Sanction^{k}_{ij,t-n}$, exerting a disruptive impact on bilateral trade between the sender and target countries. Notably, our analysis reveals an interesting trend in the coefficient, indicating a growing impact over time. Specifically, it rises from an immediate 90 percent effect to 95 percent after four years, eventually decreasing to a 66 percent impact after five years[5].

Concerning the possible trade diversion arising from trade sanctions, both the sender and target countries, when faced with sanctions, might seek to redirect trade towards alternative source countries or recipients, respectively.

When examining the influence of trade sanctions on bilateral trade with countries not subjected

[4] To avoid perfect collinearity between our variables of interest and the included fixed effects, we define product fixed effects at a more aggregate level, HS-2 digit.

[5] All percentages are calculated from the formula: (exp($\hat{\beta}$)-1)x100.

to sanctions, we observe that the coefficient of the dummy $Sender^k_{i,z\neq j,t-n}$ is consistently negative and statistically significant across columns (2) to (5). The pattern shown in Table 3 suggests a progressive decline in trade, ranging from 27 percent to 47 percent, as time elapses.

Table 3: Trade effects of trade sanctions. Gravity model with fixed effects

	(1) no lag $(n = 0)$	(2) 1-year lag $(n = 1)$	(3) 2-year lag $(n = 2)$	(4) 3-year lag $(n = 3)$	(5) 4-year lag $(n = 4)$	(6) 5-year lag $(n = 5)$
$Sanction^k_{ij,t-n}$	-2.35***	-2.43***	-2.66***	-2.85***	-2.98***	-1.09**
	(0.37)	(0.37)	(0.35)	(0.33)	(0.4933)	(0.54)
$Sender^k_{i,z\neq j,t-n}$	-0.24	-0.32*	-0.42**	-0.55***	-0.63***	-0.61
	(0.19)	(0.18)	(0.19)	(0.20)	(0.20)	(0.18)
$Target^k_{c\neq i,j,t-n}$	0.95*	0.78	0.59	0.43	0.28	0.42
	(0.58)	(0.62)	(0.70)	(0.80)	(0.82)	(0.70)
N	1,684,457	1,525,005	1,369,023	1,214,285	1,054,900	895,770
pseudo R^2	0.70	0.70	0.70	0.70	0.70	0.69

Notes: Robust standard errors clustered by country-pairs in parentheses; Included (unreported) are constant and importer-product-time; exporter-product-time and importer-exporter-time fixed effects; * $p < 0.10$, ** $p < 0.05$,*** $p < 0.01$.

The coefficient associated with the dummy variable $Target^k_{c\neq i,j,t-n}$, representing the impact of sanctions on trade between the target country and third countries, consistently shows a positive sign. However, it is statistically significant, at the 10 percent level of confidence, only in column (1). This implies that the target country rapidly shifts its trade toward other countries, leading to a trade flow increase of approximately 61 percent.

5.1 Disaggregating by HS chapters

Table 4 shows the trade impact of trade sanctions on various products. For a more comprehensive analysis, Appendix C provides results for the impact on specific sanctioned products defined at the 4-HS digit level. Findings presented in Table 4 suggest that sanctions are linked to a substantial reduction in the trade of two categories: Ores, slag, and ash commodities (Chapter 26 HS classification) and Mineral Fuels, Mineral Oils, and Products of Their Distillation; Bituminous Substances; Mineral Waxes (Chapter 27 HS classification). Specifically, the estimated coefficients for these categories are -1.64 (corresponding to a trade reduction of approximately 81 percent) and -4.54 (corresponding to a trade reduction of approximately 99 percent), respectively, and they are statistically significant.

Not all raw materials are affected by trade diversion to the same extent, as highlighted in the analysis so far. Countries that impose sanctions on commodities under Chapter 25 of the HS classification, which includes "Salt; sulfur; earth and stone; plastering materials, lime, and cement" can source them from other countries. The estimated coefficient indicates an increase in trade of around 70 percent. However, for commodities classified under Chapter 27, specifically "Coal; briquettes, ovoids, and similar solid fuels manufactured from coal" and "Coke and semi-coke; of coal, lignite, or peat" (refer to Appendix C for details), there is evidence of significant trade disruption, approximately 87 percent.

Table 4: Trade Effects of trade sanctions by product.

	Chapter 25: Salt; sulfur; earths and stone; plastering materials, lime and cement	Chapter 26: Ores, slag and ash	Chapter 27: Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes
$Sanction^k_{ij,t-1}$	0.19	-1.64***	-4.54***
	(0.46)	(0.45)	(0.42)
$Sender^k_{i,z\neq j,t-1}$	0.53***	-0.20	-2.07***
	(0.13)	(0.17)	(0.59)
$Target^k_{c\neq i,j,t-1}$	-0.27	1.74***	-4.04***
	(0.19)	(0.49)	(0.63)
N	801,553	702,335	21,087
pseudo R^2	0.54	0.54	0.84

Notes: Robust standard errors clustered by country-pairs in parentheses; Included (unreported) are constant and importer-product-time; exporter-product-time and importer-exporter-time fixed effects; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Concerning the diversion of target countries, the table highlights that target countries of commodities under Chapter 26 manage to supply other destination markets, achieving a trade diversion of approximately 470 percent. In contrast, suppliers of commodities falling under Chapter 27 experience a sharp reduction in their exports, roughly around 98 percent, indicating difficulties in exporting them to alternative destinations.

5.2 Disaggregating by world regions: the sender's perspective.

To test the general validity of our results, we have re-run our estimations by highlighting regional patterns.

Table 5 shows the results of trade effects from the sender's perspective. Specifically, it provides an overview of the various repercussions stemming from trade sanctions enforced by different senders (i) on bilateral trade ($Sanction^k_{ij,t-n}$). Additionally, the table highlights the effects on trade between the different senders (i) and third countries ($Sender^k_{i,z\neq j,t-n}$), as well as the effects on trade between the target countries and various OECD member destinations (c) that do not take part into the sanctioning mechanism ($Target^k_{c\neq i,j,t-n}$).

Trade sanctions from both EU member states and countries in the Asia and Pacific region have a clear and statistically significant adverse impact on trade. Particularly, when a sender is from the Asia and Pacific region, especially Japan and Australia in our sample, the negative effect becomes even more pronounced. In such cases, trade can decrease by approximately 95 percent when imposed by EU members and around 98 percent when imposed by Japan and Australia. Sanctions enforced by the remaining European countries (in our sample, Iceland, Norway, Switzerland, and Turkey) appear to have a detrimental effect on trade in the medium to long term. Such evidence is displayed in columns (5) and (6) and the coefficients point to an average impact of 82 percent decrease in trade.

Interestingly, sanctions imposed by North American countries, specifically Canada and the USA, yield a positive estimated coefficient; however, this result lacks statistical significance.

An examination of the impact of trade sanctions on trade interactions involving different senders and non-sanctioned countries, commonly referred to as the sender's trade diversion effect, reveals that North American countries applying trade sanctions demonstrate a greater ability to redirect trade flows from alternative source countries. This is evident in the consistently positive and statistically significant estimated coefficient ($Sender^k_{i,z\neq j,t-n}$) for North America across all model specifications (columns 1 through 6). The resulting trade diversion in North America averaged around 170 percent over the first five years after the imposition of the sanctions.

Conversely, EU member states that impose sanctions not only experience a reduction in trade with target countries but also a decrease in trade with other trading partners, amounting to a reduction of approximately 44 percent. This reduction results from the consistently negative and statistically significant coefficient ($Sender^k_{i,z\neq j,t-n}$) for the EU members.

On the other hand, target countries redirect their trade to different locations. Specifically, the estimated coefficients of the dummy variable $Target^k_{c\neq i,j,t-n}$ in Table 5 reveal that target countries witness a substantial decrease in trade with countries located in Europe, with an average decrease of -90 percent. They also observe a significant decrease in trade with countries in the Middle East, such as Israel in our sample, showing a decrease of approximately -100 percent. Simultaneously, they expand their trade ties with partners in the EU, realizing an increase of around 600 percent, North America, with an increase of around 300 percent, and the Latin America and Caribbean regions, namely Chile, Colombia, Costa Rica, and Mexico, with an increase of around 300 percent. These significant increases can also be attributed to rising prices.

Table 5: Trade Effects from the Sender's Perspective

	(1)	(2)	(3)	(4)	(5)	(6)
	no lag	1-year lag	2-year lag	3-year lag	4-year lag	5-year lag
	$(n=0)$	$(n=1)$	$(n=2)$	$(n=3)$	$(n=4)$	$(n=5)$
$Sanction^k_{ij,t-n}$, **with** $i =$						
EU	-2.86***	-2.84***	-2.95***	-2.97***	-3.01***	-2.87***
	(0.25)	(0.28)	(0.29)	(0.27)	(0.25)	(0.29)
Asia&Pacific	-3.72***	-4.09***	-4.39***	-4.56***	-4.53***	-4.48***
	(0.22)	(0.19)	(0.14)	(0.11)	(0.10)	(0.11)
Europe	-1.00	-0.92	-0.76	-0.62	-1.56*	-1.84**
	(0.71)	(0.69)	(0.65)	(0.63)	(0.88)	(0.83)
NorthAmerica	0.47	0.47	0.58	0.54	0.38	0.43
	(0.66)	(0.72)	(0.83)	(1.04)	(1.32)	(0.1.35)
$Sender^k_{i,z\neq j,t-n}$, **with** $i =$						
EU	-0.42***	-0.50***	-0.59***	-0.68***	-0.73***	-0.76***
	(0.10)	(0.11)	(0.11)	(0.12)	(0.12)	(0.12)

Asia&Pacific	-0.21	-0.28	-0.45	-0.68	-0.85*	-0.86*
	(0.50)	(0.50)	(0.51)	(0.52)	(0.51)	(0.48)
Europe	-0.31	-0.33	-0.33	-0.36	-0.42	-0.45
	(0.42)	(0.41)	(0.41)	(0.41)	(0.41)	(0.42)
NorthAmerica	1.02***	0.93***	0.91***	0.93***	0.97***	0.97***
	(0.17)	(0.13)	(0.11)	(0.12)	(0.13)	(0.12)
$Target^k_{c\neq i,j,t-n}$, **with** $c =$						
EU	1.21***	1.36***	1.58***	1.82***	2.18***	2.43***
	(0.34)	(0.36)	(0.38)	(0.41)	(0.46)	(0.47)
Asia&Pacific	1.06	0.89	0.68	0.49	0.24	0.20
	(0.73)	(0.80)	(0.93)	(1.08)	(1.15)	(1.01))
Europe	-1.40	-1.95*	-2.52***	-2.70***	-2.70***	-2.54***
	(1.18)	(1.10)	(0.74)	(0.31)	(0.12)	(0.14)
LatinAmerica&Caribbean	1.38***	0.70	0.62	0.74	1.28*	1.56**
	(0.53)	(0.52)	(0.59)	(0.78)	(0.76)	(0.68)
MiddleEast	0.34	0.45	-0.03	-0.05	-5.26***	-4.81***
	(0.58)	(0.61)	(0.30)	(0.24)	(0.23)	(0.18)
NorthAmerica	1.31***	1.35**	1.37**	1.41**	1.43**	1.39**
	(0.47)	(0.56)	(0.61)	(0.65)	(0.68)	(0.68)
N	1,684,457	1,525,005	1,369,023	1,214,285	1,054,900	895,770
pseudo R^2	0.70	0.70	0.70	0.70	0.70	0.70

Notes: Robust standard errors clustered by country-pairs in parentheses; Included (unreported) are constant and importer-product-time; exporter-product-time and importer-exporter-time fixed effects; * $p < 0.10$, ** $p < 0.05$,*** $p < 0.01$.

Table 6 shows the consequences of trade sanctions from the target's perspective. It illustrates how these sanctions, $Sanction^k_{ij,t-n}$, affect various target countries, j. Furthermore, the table shows the impact on trade resulting from the redirection of trade by senders, $Sender^k_{i,z\neq j,t-n}$, towards other destinations not subject to sanctions, z.

It also highlights the effect on trade between the target countries, j, and various OECD member destinations not involved in the sanction agreement, thus emphasizing the different trade diversion effects among target countries, $Target^k_{c\neq i,j,t-n}$.

5.3 Disaggregating by world regions: the target's perspective.

From the target's perspective, Table 6 reveals that the most affected target countries are the exporters in the Europe and Central Asia region. Notably, the Russian Federation and Ukraine are the major target countries. The coefficient of the dummy variable $Sanction^{k}_{ij,t-n}$ points to a decrease in trade ranging from 96 percent (in column (1)) to 97 percent (in column (6)). Following closely are countries in the Sub-Saharan Africa region, where the most sanctioned countries are Guinea and Zimbabwe. In this area, the initial decrease in trade is approximately 88 percent.

Strikingly, Middle Eastern and North African countries, namely Egypt Arab Rep, Iran Islamic Rep., Israel, and Saudi Arabia, are experiencing an unexpected increase in trade despite sanctions, which provides some evidence of sanction busting. This finding also raises questions about potential efforts to bypass or evade the sanctions, particularly in resource-rich areas.

Looking at the estimated coefficients of the dummy variable $Sender^{k}_{i,z\neq j,t-n}$, it becomes apparent that mineral exporters in the Middle East and North Africa regions are enjoying the most substantial gains from potential trade diversion due to sanctions. Conversely, international trade in sender countries is decreasing, particularly in Europe, Central Asia, and Sub-Saharan Africa, likely due to rising mineral commodity prices.

In response to evolving global trade dynamics, target countries are actively redirecting their trade patterns. This shift is particularly evident in the East Asia and Pacific regions, where China plays a central role in global trade. The coefficients representing this trade redirection, denoted as $Target^{k}_{c\neq i,j,t-n}$, are not only statistically significant but also show a consistent upward trend over time. The same holds for sub-Saharan African countries, which are particularly rich in natural resources. Therefore, target countries in the region could redirect their trade to meet the growing global demand for raw materials, especially minerals. This may involve the establishment of new trade relationships with countries that require these resources.

Meanwhile, trade with countries in other regions gradually declined, indicating challenges in diverting trade to alternative destinations.

Table 6: Trade Effects from the Target's Perspective

	(1)	(2)	(3)	(4)	(5)	(6)
	no lag	1-year lag	2-year lag	3-year lag	4-year lag	5-year lag

	$(n=0)$	$(n=1)$	$(n=2)$	$(n=3)$	$(n=4)$	$(n=5)$
$Sanction^k_{ij,t-n}$, **with** $j=$						
$EastAsia\&Pacific$	-0.33	-0.21	0.25	0.99	-0.27	0.33
	(0.60)	(0.63)	(0.68)	(0.79)	(0.93)	(0.73)
$Europe\&CentralAsia$	-3.26***	-3.26***	-3.38***	-3.40***	-3.47***	-3.46***
	(0.25)	(0.29)	(0.29)	(0.29)	(0.26)	(0.25)
$LatinAmerica\&Caribbean$	-0.41	-0.38	-0.50	-0.56	-0.58	-0.56
	(1.63)	(1.65)	(1.62)	(1.59)	(1.60)	(1.59)
$MiddleEast\&NorthAfrica$	0.94**	0.85**	0.79**	0.92**	0.94**	0.86**
	(0.44)	(0.39)	(0.37)	(0.38)	(0.37)	(0.38)
$Sub-SaharanAfrica$	-2.11***	-1.80*	-0.43	-0.41	-0.45	-0.06
	(0.79)	(0.95)	(1.06)	(1.08)	(1.06)	(1.03)
$Sender^k_{i,z\neq j,t-n}$, **with** $z=$						
EU	0.10	0.07	0.07	0.09	0.05	-0.04
	(0.14)	(0.15)	(0.17)	(0.18)	(0.18)	(0.17)
$EastAsia\&Pacific$	-0.63	-0.70	-0.85*	-1.08**	-1.20**	-1.14**
	(0.48)	(0.49)	(0.51)	(0.51)	(0.50)	(0.48)
$Europe\&CentralAsia$	-0.58***	-0.69***	-0.83***	-0.99***	-1.04***	-0.98***
	(0.20)	(0.21)	(0.23)	(0.25)	(0.26)	(0.28)
$LatinAmerica\&Caribbean$	0.05	-0.04	-0.12	-0.20	-0.33	-0.42
	(0.38)	(0.35)	(0.34)	(0.34)	(0.32)	(0.30)
$MiddleEast\&NorthAfrica$	0.62***	0.51**	0.39*	0.29	0.11	-0.00
	(0.21)	(0.21)	(0.22)	(0.25)	(0.27)	(0.26)
$NorthAmerica$	0.04	-0.03	-0.21	-0.39	-0.47	-0.39
	(0.28)	(0.28)	(0.28)	(0.31)	(0.33)	(0.35)
$SouthAsia$	-0.88*	-0.91*	-0.92*	-0.89	-0.80	-0.74
	(0.49)	(0.51)	(0.52)	(0.56)	(0.63)	(0.62)
$Sub-SaharanAfrica$	-0.83***	-0.85***	-1.00***	-0.96***	-0.80	-0.90***
	(0.28)	(0.28)	(0.29)	(0.30)	(0.29)	(0.29)
$Target^k_{c\neq i,j,t-n}$, **with** $j=$						
$EastAsia\&Pacific$	2.39***	2.50***	2.74***	3.52***	3.73***	3.03***
	(0.71)	(0.69)	(0.63)	(0.76)	(0.50)	(0.37)

Europe&CentralAsia	-0.61	-1.07	-1.42*	-1.71**	-1.82**	-1.47*
	(0.67)	(0.75)	(0.76)	(0.76)	(0.78)	(0.88)
LatinAmerica&Caribbean	-0.74	-0.77*	-0.82*	-0.99**	-1.05***	-1.09***
	(0.53)	(0.47)	(0.43)	(0.41)	(0.39)	(0.37)
MiddleEast&NorthAfrica	-0.41	-1.04***	-0.95***	-0.45	-0.49	-0.48
	(0.69)	(0.36)	(0.30)	(0.49)	(0.49)	(0.52)
$Sub-SaharanAfrica$	1.59***	2.04***	3.50***	3.59***	3.70***	3.98***
	(0.42)	(0.42)	(0.53)	(0.55)	(0.52)	(0.42)
N	1,684,278	1,524,871	1,368,898	1,214,285	1,054,900	895,770
pseudo R^2	0.700	0.699	0.700	0.701	0.700	0.697

Notes: Robust standard errors clustered by country-pairs in parentheses; Included (unreported) are constant and importer-product-time; exporter-product-time and importer-exporter-time fixed effects; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6 Conclusion

This article conducts an empirical examination of the impact of economic sanctions on the trade of mineral commodities spanning the period 2009-2020. Employing an augmented gravity model, we underscore the extent of trade disruption between sender and target countries and explore the emergence of trade diversion attributed to sanctions circumvention.

Differently from the existing literature, we aim to provide a more comprehensive analysis of the impact of sanctions by disaggregating mineral trade down to the six-digit level of the Harmonised System (HS). To achieve this, we have defined a dummy variable that combines the presence of complete sanctions between importer and exporter with any trade restrictions on specific mineral commodities. We have integrated data from the OECD Inventory of export restrictions on industrial raw materials and the Global Sanctions Database (GSDB). Upon imposition, sanctions prompt a significant trade disruption in the short run, evidenced by an immediate 90 percent reduction, with the negative impact intensifying over time. There is also weak evidence regarding sanctions-busting. As noted above, our study contributes to the literature also by examining trade diversion for sender countries, an aspect previously underexplored. In practice, we scrutinize whether sender countries substitute imports from target countries with those from third-party countries. Empirical results unveil a nuanced outcome, indicating a decline in trade for sender countries not only with target countries but also with third-party countries, suggesting a negative network effect—sanctions engender broad trade disruption. However, a detailed analysis by world regions and HS chapters introduces complexity. North American countries demonstrate the capacity to replace imports from target countries with alternative suppliers, contrasting with distinct trade disruption experienced by EU countries. Evidence remains inconclusive regarding sanctions evasion for most regions, except for MENA countries, where an increase in mineral exports is observed despite sanctions.

Findings on different commodities reveal that sanctions lead to reduced trade in mineral commodities under Chapters 26 and 27, but not those under Chapter 25. Sanctions evasion appears primarily operative for commodities under Chapter 26. Sender countries importing commodities under Chapter 25 exhibit the ability to shift to alternative sources, whereas those importing commodities under Chapter 27 face significant trade disruption, indicating challenges in alternative supply channel adoption. Target countries exporting commodities under Chapter 26 manage to supply other markets, achieving trade diversion likely due to sanctions evasion. Conversely, suppliers of commodities under Chapter 27 experience a sharp decline in exports, approximately 98 percent.

References

Afesorgbor, S. K. (2019). The impact of economic sanctions on international trade: How do threatened sanctions compare with imposed sanctions? *European Journal of Political Economy*, 56:11–26.

Afesorgbor, S. K. and Mahadevan, R. (2016). The impact of economic sanctions on income inequality of target states. *World Development*, 83:1–11.

Bapat, N. A., Tobias, H., Yoshiharu, K., and Morgan, T. C. (2013). Determinants of sanctions effectiveness: Sensitivity analysis using new data. *International Interactions*, 39(1):79–98.

Bonetti, S. (1998). Distinguishing characteristics of degrees of success and failure in economic sanctions episodes. *Applied Economics*, 30(6):805–813.

Campos, R. G., Timini, J., and Vidal, E. (2021). Structural gravity and trade agreements: Does the measurement of domestic trade matter? *Economics Letters*, 208:110080.

Caruso, R. (2003). The impact of international economic sanctions on trade: An empirical analysis. *Peace Economics Peace Science and Public Policy*, 9(2).

Cheng, I.-H. and Wall, H. (2005). Controlling for heterogeneity in gravity models of trade and integration. *Review*, 87(Jan):49–63.

Doan, N. T. and Tran, M. H. (2023). Quantifying the effect of economic sanctions on trade in cultural goods. *International Economic Journal*, 37(3):401–423.

Du, X. and Wang, Z. (2022). Multinationals, global value chains, and the welfare impacts of economic sanctions. *Economics Letters*, 220:110870.

Early, B. R. (2015). *Busted Sanctions: Explaining Why Economic Sanctions Fail.* Stanford University Press.

Egger, P. H., Larch, M., and Yotov, Y. V. (2022). Gravity estimations with interval data: Revisiting the impact of free trade agreements. *Economica*, 89(353):44–61.

Evenett, S. J. (2002). The impact of economic sanctions on south african exports. *Scottish Journal of Political Economy*, 49(5):557–573.

Fally, T. (2015). Structural gravity and fixed effects. *Journal of International Economics*, 97(1):76–85.

Felbermayr, G., Kirilakha, A., Syropoulos, C., Yalcin, E., and Yotov, Y. V. (2020a). The global sanctions data base. *European Economic Review*, 129:103561.

Felbermayr, G., Syropoulos, C., Yalcin, E., and Yotov, Y. (2020b). On the Heterogeneous Effects of Sanctions on Trade and Welfare: Evidence from the Sanctions on Iran and a New Database. School of Economics Working Paper Series 2020-4, LeBow College of Business, Drexel University.

Gharehgozli, O. (2017). An estimation of the economic cost of recent sanctions on iran using the synthetic control method. *Economics Letters*, 157:141–144.

Golub, J. (2020). Improving analyses of sanctions busting. *Peace Economics, Peace Science and Public Policy*, 26(2):20190043.

Head, K. and Mayer, T. (2014). Gravity equations: Workhorse,toolkit, and cookbook. volume 4, chapter Chapter 3, pages 131–195. Elsevier.

Heid, B., Larch, M., and Yotov, Y. V. (2021). Estimating the effects of non-discriminatory trade policies within structural gravity models. *Canadian Journal of Economics/Revue canadienne d'économique*, 54(1):376–409.

Hufbauer, G. C., Schott, J. J., and Elliott, K. A. (1990). *Economic sanctions reconsidered: History and current policy*, volume 1. Peterson Institute.

Isard, W. (1954). Location Theory and Trade Theory: Short-Run Analysis. *The Quarterly Journal of Economics*, 68(2):305–320.

Islam, M. M., Sohag, K., Hammoudeh, S., Mariev, O., and Samargandi, N. (2022). Minerals import demands and clean energy transitions: A disaggregated analysis. *Energy Economics*, 113:106205.

Jeong, J. M. (2020). Economic sanctions and income inequality: impacts of trade restrictions and foreign aid suspension on target countries. *Conflict Management and Peace Science*, 37(6):674–693.

Kelishomi, A. M. and Nisticò, R. (2022). Employment effects of economic sanctions in iran. *World Development*, 151:105760.

Kim, J., Kim, K., Park, S., and Sun, C. (2023). The economic costs of trade sanctions: Evidence from north korea. *Journal of International Economics*, 145:103813.

Larch, M., Shikher, S., Syropoulos, C., and Yotov, Y. V. (2022). Quantifying the impact of economic sanctions on international trade in the energy and mining sectors. *Economic Inquiry*, 60(3):1038–1063.

Linnemann, H. (1966). *An Econometric Study of International Trade Flows.* North Holland, Amsterdam.

Miromanova, A. (2023). Quantifying the trade-reducing effect of embargoes: Firm-level evidence from russia. *Canadian Journal of Economics/Revue canadienne d'économique*, 56(3):1121–1160.

Moeeni, S. (2021). The Intergenerational Effects of Economic Sanctions. *The World Bank Economic Review*, 36(2):269–304.

Morgan, T. C., Syropoulos, C., and Yotov, Y. V. (2023). Economic sanctions: Evolution, consequences, and challenges. *The Journal of Economic Perspectives*, 37(1):pp. 3–30.

Moroney, J. R. and Trapani, J. M. (1981). Factor demand and substitution in mineral-intensive industries. *The Bell Journal of Economics*, 12(1):272–284.

Neuenkirch, M. and Neumeier, F. (2015). The impact of un and us economic sanctions on gdp growth. *European Journal of Political Economy*, 40:110–125.

Neuenkirch, M. and Neumeier, F. (2016). The impact of us sanctions on poverty. *Journal of Development Economics*, 121:110–119.

Nguyen, T. T. and Do, M. H. (2021). Impact of economic sanctions and counter-sanctions on the russian federation's trade. *Economic Analysis and Policy*, 71:267–278.

Pape, R. A. (1997). Why economic sanctions do not work. *International Security*, 22(2):90–136.

Pöyhönen, P. (1963). A tentative model for the volume of trade between countries. *Weltwirtschaftliches Archiv*, 90:93–100.

Silva, J. S. and Tenreyro, S. (2006). The log of gravity. *The Review of Economics and statistics*, 88(4):641–658.

Stuermer, M. (2017). Industrialization and the demand for mineral commodities. *Journal of International Money and Finance*, 76:16–27.

Tinbergen, J. (1962). *Shaping the World Economy; Suggestions for an International Economic Policy.* T.

Van Bergeijk, P. A. G. (1994a). *Economic Diplomacy, Trade and Commercial Policy.* Edward Elgar Publishing.

Van Bergeijk, P. A. G. (1994b). Effectivity of economic sanctions: Illusion or reality? *Peace Economics, Peace Science and Public Policy*, 2(1):24–35.

Van Bergeijk, P. A. G. (1995). The impact of economic sanctions in the 1990s. *The World Economy*, 18(3):443–455.

Yotov, Y. V., Piermartini, R., Monteiro, J.-A., and Larch, M. (2016). *An advanced guide to trade policy analysis: The structural gravity model.* World Trade Organization Geneva.

APPENDIX

A Commodity description

Table 1: Product classification

Section V	Minerals (industrial raw materials)	HS6 code
Chapter 25	Salt; sulfur; earths and stone; plastering materials, lime and cement	250200; 250410; 250490; 250510; 250590; 250700; 250810; 251010; 251020; 251110; 251320; 251910; 251990; 252010; 252020; 252100; 252210; 252220; 252230; 252610; 252620; 252810; 252890; 252910; 252921; 252922; 252930; 253090.
Chapter 26	Ores, slag and ash	260111; 260112; 260120; 260200; 260300; 260400; 260500; 260600; 260700; 260800; 260900; 261000; 261100; 261310; 261390; 261400; 261510; 261590; 261610; 261690; 261710; 261790; 261800; 261900; 262011; 262019; 262021; 262029; 262030; 262040; 262060; 262091; 262099.
Chapter 27:	Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes	270112; 270400.

Table 2: List of countries subject to trade sanctions ($Sanction_{ij,t}^{k} = 1$)

Senders	Freq.	Targets	Freq.
United States	1,740	Russian Federation	2,483
Canada	494	Zimbabwe	1,872
United Kingdom	368	Egypt, Arab Rep.	1,810
Spain	362	Myanmar	1,116
France	306	Iran, Islamic Rep.	600
Germany	303	Guinea	402
Czech Republic	298	Cuba	384
Italy	298	Korea, Dem. Rep.	344
Luxembourg	298	Ukraine	226
Netherlands	298	Armenia	204
Poland	298	Israel	140
Slovak Republic	298	China	134
Belgium	296	Nigeria	80
Denmark	295	Indonesia	78
Slovenia	292	Congo, Dem. Rep.	60
Turkey	292	Bolivia	56
Ireland	289	Saudi Arabia	48
Greece	288	Fm Sudan	45
Finland	283	Jamaica	30
Sweden	283	Colombia	22
Portugal	273	Vietnam	17
Hungary	263	Ghana	15
Austria	256	Sierra Leone	12
Estonia	253	South Africa	6
Latvia	253	Turkey	3
Lithuania	252	Kyrgyz Republic	1
Norway	232		
Switzerland	196		
Japan	184		
Iceland	174		
Korea, Rep.	88		
Australia	85		
Overall	10,188		10,188

B Gravity model

The results of the baseline gravity model - which includes bilateral distance and other gravity controls - are presented in Table 3. Column (1) shows the results for the full sample without any lags applied to the interest variables related to the trade sanction. In the other columns, we introduce a one-year lag (Column (2) and continue this pattern until the five-year lag (Column (5)) is incorporated. The use of lagged values of the $Sanction^k_{ij,t}$ relies on the intuitive argument that dependent and independent variables cannot fully adjust within 1 year.

The negative and significant coefficient of the dummy $Sanction^k_{ij,t-n}$ highlights that a sanction disrupts bilateral trade in the very short run, by around 90 percent (in Column (1)), and up to 94 percent after four years (Column (5)).

The coefficient of the dummy $Sender^k_{i,z\neq j,t-n}$ is negative and statistically significant. It indicates that after one year and up to four years following the imposition of a sanction, there is a reduction in trade not only between the countries involved in the sanctioning provision but also with third countries (negative network effects). Specifically, a trade sanction results in a reduction of trade for the senders, ranging from approximately 27 percent after one year to around 46 percent after four years. There is no evidence of trade diversion. The estimated coefficient of the variable $Target^k_{c\neq i,j,t-n}$, related to the trade diversion of the target, is positive even if not statistically significant.

Table 3: Trade effects of trade sanctions. Model with gravity controls

	(1) no lag ($n=0$)	(2) 1-year lag ($n=1$)	(3) 2-year lag ($n=2$)	(4) 3-year lag ($n=3$)	(5) 4-year lag ($n=4$)	(6) 5-year lag ($n=5$)
$Sanction^k_{ij,t-n}$	-2.32***	-2.30***	-2.39***	-2.54***	-2.73***	-2.68
	(0.36)	(0.36)	(0.34)	(0.31)	(0.29)	(0.32)
$Sender^k_{i,z\neq j,t-n}$	-0.24	-0.31**	-0.41***	-0.52***	-0.62***	-0.60
	(0.16)	(0.15)	(0.16)	(0.17)	(0.17)	(0.15)
$Target^k_{c\neq i,j,t-n}$	0.14	0.11	0.11	0.13	0.14	0.11
	(0.29)	(0.29)	(0.30)	(0.35)	(0.37)	(0.31)
$ln(Distance_{ij})$	-0.86***	-0.86***	-0.86***	-0.86***	-0.86***	-0.85***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
$ln(GDP_{i,t})$	0.25	0.16	0.05	-0.01	-0.18	0.02
	(0.16)	(0.17)	(0.18)	(0.19)	(0.25)	(0.24)
$ln(GDP_{j,t})$	-0.09	-0.04	-0.00	-0.01	0.01	0.07
	(0.16)	(0.16)	(0.16)	(0.17)	(0.16)	(0.15)
$Contiguity_{ij}$	1.06***	1.05***	1.04***	1.01***	1.00***	1.00***
	(0.17)	(0.18)	(0.18)	(0.18)	(0.18)	(0.19)
$Languange_{ij}$	0.52***	0.53***	0.54***	0.57***	0.57***	0.59***
	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
$Colony_{ij}$	0.14	0.13	0.12	0.09	0.08	0.07
	(0.34)	(0.34)	(0.33)	(0.33)	(0.33)	(0.33)
N	2,688,207	2,462,784	2,237,089	2,009,830	1,784,917	1,559,169
R^2	0.60	0.60	0.60	0.60	0.60	0.60

Notes: Robust standard errors clustered by country-pairs in parentheses; Included (unreported) are constant and importer, exporter, product and time fixed effects;
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

As regards the results of the gravity variables, the coefficient of the bilateral distance between countries indicated with $Distance_{ij}$ is negative and significant, correctly capturing the larger trade costs implied by distance. As expected, the economic variables *Contiguity* and *Language*, have a positive and significant impact on bilateral trade, indicating that when two countries have a land border or share the same language, trade flows is higher; while, economic sizes ($ln(GDP_{i,t})$ and $ln(GDP_{j,t})$) and colonial ties, $Colony_{ij}$, seem to not affect trade.

In Table 4, we employ a gravity equation to estimate the trade impact of sanctions using aggregated data from the GSDB. The results consistently demonstrate a negative and statistically significant impact.

Table 4: Trade effects of trade sanctions.

	(1) no lag	(2) 1-year lag	(3) 2-year lag	(4) 3-year lag	(5) 4-year lag	(6) 5-year lag
$Sanction^k_{ij,t}$	-2.24***	-2.19***	-2.25***	-2.36***	-2.52***	-2.47***
	(0.36)	(0.36)	(0.34)	(0.31)	(0.30)	(0.32)
$ln(Distance_{ij})$	-0.86***	-0.86***	-0.86***	-0.86***	-0.86***	-0.85***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
$ln(GDP_{i,t})$	0.33*	0.28*	0.22	0.23	0.10	0.04
	(0.17)	(0.17)	(0.18)	(0.19)	(0.24)	(0.25)
$ln(GDP_{j,t})$	-0.08	-0.04	-0.01	-0.02	-0.01	0.07
	(0.15)	(0.16)	(0.16)	(0.17)	(0.16)	(0.15)
$Contiguity_{ij}$	1.06***	1.05***	1.04***	1.01***	1.01***	1.00***
	(0.17)	(0.18)	(0.18)	(0.18)	(0.18)	(0.19)
$Language_{ij}$	0.52***	0.53***	0.54***	0.57***	0.57***	0.59***
	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
$Colony_{ij}$	0.14	0.13	0.12	0.09	0.08	0.07
	(0.34)	(0.34)	(0.33)	(0.33)	(0.33)	(0.32)
N	2,688,207	2,462,784	2,237,089	2,009,830	1,784,917	1,559,169
pseudo R^2	0.60	0.60	0.60	0.60	0.59	0.59

Notes: Robust standard errors clustered by country-pairs in parentheses; $Sanction^k_{ij,t}$ from the GSBD; Included (unreported) are constant and importer, exporter, product, and year fixed effects;
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

C Trade effect of trade sanctions: industry-wise analysis

Table 5: Trade Effects of trade sanctions by product (HS4-digit).

	(1) Estimated coefficient	(2) Standard errors
$Sanction^k_{ij,t-1}$:		
Natural sands of all kinds (2505)	-2.80***	(0.16)
Gypsum; anhydrite; plasters (2520)	-5.36***	(0.49)
Natural steatite (2526)	-0.75***	(0.25)

Natural borates and concentrates thereof (2528)	7.30***	(0.27)
Feldspar; leucite; nepheline and nepheline syenite; fluorspar (2529)	-0.85***	(0.14)
Mineral substances not elsewhere specified or included (2530)	-0.93***	(0.16)
Iron ores and concentrates (2601)	-5.21***	(1.13)
Copper ores and concentrates (2603)	-2.55***	(0.58)
Nickel ores and concentrates (2604)	-3.97***	(0.84)
Aluminium ores and concentrates (2606)	3.26***	(0.57)
Zinc ores and concentrates (2608)	-3.85***	(0.75)
Molybdenum ores and concentrates (26013)	-8.80***	(0.76)
Titanium ores and concentrates (26014)	-1.13*	(0.60)
Precious metal ores and concentrates (26016)	-1.80***	(0.64)
Ores and concentrates (2617)	-2.21**	(1.05)
Slag, dross; (other than granulated slag), scalings and other waste (2619)	-2.30*	(1.34)
Slag and ash (2621)	-3.23***	(0.56)
Coke and semi-coke; of coal, lignite or peat; retort carbon (2704)	-4.39***	(0.37)
$Sender^k_{i,z\neq j,t-1}$:		
Unroasted iron pyrites (2502)	-2.69***	(0.53)
Kaolin and other kaolinic clays (2507)	1.36***	(0.20)
Natural calcium phosphates (2510)	0.73**	(0.32)
Natural barium sulphate (2511)	1.51***	(0.54)
Natural magnesium carbonate (2519)	1.08***	(0.25)
Limestone flux; limestone and other calcareous stone (2521)	-0.84*	(0.52)
Natural steatite (2526)	0.94***	(0.26)
Iron ores and concentrates (2601)	1.67***	(0.29)
Copper ores and concentrates (2603)	2.03***	(0.30)
Nickel ores and concentrates (2604)	-1.05**	(0.44)
Cobalt ores and concentrates (2605)	-2.75***	(0.78)
Zinc ores and concentrates (2608)	1.04***	(0.26)
Tin ores and concentrates (2609)	-5.99***	(0.32)
Chromium ores and concentrates (2610)	-1.71***	(0.36)
Tungsten ores and concentrates (2611)	-2.49***	(0.42)
Titanium ores and concentrates (2614)	1.45***	(0.54)
Niobium, tantalum, vanadium or zirconium ores and concentrates (2615)	-0.89**	(0.40)
Ores and concentrates (2617)	-3.70***	(0.32)
Granulated slag (slag sand) from the manufacture of iron or steel (2618)	-2.00***	(0.22)
Slag, dross; (other than granulated slag), scalings and other waste (2619)	-2.63***	(0.35)
Slag, ash and residues; (not from the manufacture of iron or steel) (2620)	-1.02***	(0.27)
Coke and semi-coke; of coal, lignite or peat; retort carbon (2704)	-2.27***	(0.52)
$Target^k_{c\neq i,j,t-1}$:		
Unroasted iron pyrites (2502)	-10.65***	(0.32)
Natural graphite (2504)	0.89***	(0.26)
Natural sands of all kinds (2505)	-2.02***	(0.40)
Natural calcium phosphates (2510)	-0.93*	(0.52)
Natural barium sulphate (2511)	-3.09***	(0.30)
Pumice stone; emery; natural corundum (2513)	-4.63***	(1.09)
Natural magnesium carbonate calcareous stone (2519)	-1.58***	(0.41)
Limestone flux; limestone and other calcareous stone (2521)	-5.35***	(0.61)
Quicklime, slaked lime and hydraulic lime (2522)	-5.07***	(0.32)
Natural borates and concentrates thereof (2528)	4.76***	(0.46)
Mineral substances not elsewhere specified or included (2530)	0.48**	(0.20)
Iron ores and concentrates (2601)	2.13**	(1.05)
Copper ores and concentrates (2603)	4.11***	(0.86)
Cobalt ores and concentrates (2605)	3.39***	(0.90)
Aluminium ores and concentrates(2606)	3.03***	(0.44)

Tin ores and concentrate (2609)s	-7.93***	(1.09)
Tungsten ores and concentrates (2611)	-1.40***	(0.40)
Molybdenum ores and concentrates (2613)	2.09**	(0.91)
Titanium ores and concentrates (2614)	3.64***	(0.66)
Niobium, tantalum, vanadium or zirconium ores and concentrates (2615)	-0.94*	(0.52)
Ores and concentrates (2617)	-1.55*	(0.95)
Slag, ash and residues (2620)	2.83***	(0.91)
Coal; briquettes, ovoids and similar solid fuels manufactured from coal (2701)	-5.11***	(0.87)
Coke and semi-coke; of coal, lignite or peat; retort carbon (2704)	-4.32***	(0.65)
N	1,672,548	
pseudo R^2	0.73	

Notes: Robust standard errors clustered by country-pairs in parentheses; Included (unreported) are constant and importer-product-time; exporter-product-time and importer-exporter-time fixed effects; * $p < 0.10$, ** $p < 0.05$,*** $p < 0.01$; Not significant commodities not reported.