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8878
2021
February 2021

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CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
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CESifo *Working Paper No. 8878*

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Abstract

Capitalizing on the latest developments in the gravity literature, we utilize two new datasets on sanctions and trade to study the impact of economic sanctions on international trade in the mining sector, which includes oil and natural gas. We demonstrate that the gravity equation is well suited to model bilateral trade in mining and find that sanctions have been effective in impeding mining trade. Our analysis reveals that complete trade sanctions have reduced bilateral mining trade by about 44 percent on average. We also document the presence of significant heterogeneity in the effects of sanctions on mining trade across mining industries and across sanction episodes/cases, depending on the sanctioning and sanctioned countries, the type of sanctions used, and the direction of trade flows. We take a close look at the impact of recent sanctions on Iran and Russia.

JEL Codes: F100, F130, F140, F500, F510, H500, N400.

Keywords: structural gravity, sanctions, mining, oil, trade effects.

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1 Introduction

The use of economic sanctions has surged in recent years. According to *The Global Sanctions Database*, the number of publicly traceable sanction cases during the 1950-2019 time period was 1,045 of which 77 were recorded during the last three years (Felbermayr et al., 2020a, https://globalsanctionsdatabase.com). At the same time, there has been an increase in the relative popularity of sectoral, targeted, and 'smart' sanctions, which are designed to hit their intended targets while minimizing collateral damage (cf. Drezner, 2011; Ahn and Ludema, 2020).

One prominent sector that is often sanctioned is mining, which includes oil and natural gas industries. Sanctions in these industries can be especially impactful for several reasons. First, various commodities extracted from these industries serve as essential inputs to numerous manufacturing processes, supply chains, and the infrastructures of many countries. Moreover, these commodities are traded extensively in world markets (e.g., natural resource trade accounted for 20 percent of world trade) and are indispensable to nations' growth prospects (Ruta and Venables, 2012). It stands to reason then, that economic sanctions in the mining sector may several undermine economic activity and, consequently, the well-being of individuals and entities within all affected states, especially the sanctioned ones.

We contribute to the understanding of the effects of these sanctions through quantitative analysis based on comprehensive and reliable datasets. We add to the existing literature in four distinct ways. First, we provide answers to the questions of whether economic sanctions affect international trade in mining and by how much. Second, we demonstrate that the structural gravity equation of trade is an appropriate empirical tool in modeling international trade to study the impact of various policies on mining trade. Third, from a policy perspective and using sanctions as an example, we show that the methods of structural gravity can be used to obtain not only estimates of the average sanction effects, but also of heterogeneous estimates across sectors, sanction episodes/cases, sanctioning and sanctioned countries (often referred to as "senders" and "targets", respectively), types of sanctions, and direction of trade flows. Finally, the good performance of the partial equilibrium model and analysis we present here, in combination with the ability to nest the gravity model into a number of production models (including models of energy and natural resources), sets the stage for a number of extensions in future work.

To quantify the direct impact of sanctions on mining trade, we rely on the gravity equation and follow the latest developments in the gravity literature, as summarized Yotov et al. (2016). Specifically, we set up a theory-consistent econometric gravity model, where we: (i) use exporter-sector-time and importer-sector-time fixed effects to account for the unobservable multilateral resistance terms;[1] (ii) employ the Poisson Pseudo Maximum Likelihood (PPML) estimator to address the issue of heteroskedasticity in trade data and to take advantage of the information contained in the zero trade flows (which, incidentally, take a very significant fraction in the mining sector); (iii) include directional country-pair fixed effects to comprehensively account for all time-invariant bilateral trade costs and to mitigate endogeneity concerns; and (iv) use data on international and domestic trade flows for consistency with the underlying gravity theory. Our primary departure from the recommendations of Yotov et al. (2016) is that, instead of using interval data, we follow Egger et al. (2020) to obtain our estimates with consecutive-year data.

We employ two novel datasets to perform the empirical analysis. The data on trade flows come from the inaugural 2020 edition of the International Trade and Production Database for Estimation (ITPD-E), which covers consistently constructed international and domestic trade flows for 170 industries and 243 countries over the period 2000-2016. Given the focus of our study, we only utilize the data for the mining sectors from the ITPD-E.

[1] The use of country-specific fixed effects enables us to estimate the impact of sanctions on bilateral trade after controlling for all exporter-specific and importer-specific characteristics and changes, such as changes in total exports of the exporting countries and changes in total imports of the importing country. One way to think about the impact of sanctions is that they increase trade costs. We will investigate whether trade costs do indeed change after sanctions are imposed. In addition, the fact that these fixed effects are time-varying allows us to capture not only any time-varying characteristic at the country level, but also global trends such as the change in the world price of oil. See Section 2 for further details.

The data on sanctions come from the inaugural 2020 edition of the Global Sanctions Data Base (GSDB), which covers all publicly traceable sanctions over the period 1950-2016. The GSDB distinguishes between sanctions that apply only to specific goods and/or particular sector(s) of trade (partial trade sanctions) or to all sectors (complete trade sanctions). Capitalizing on the focus of the GSDB on trade sanctions we estimate average effects of trade sanctions, differential effects of complete vs. partial trade sanctions, as well as specific effects of the sanctions on Russia and Iran. Combining the two data sources results in an unbalanced panel sample covering all trade sanctions and bilateral trade in the aggregate mining sector as well as in the three sub-sectors: 'Mining of hard coal', 'Extraction crude petroleum and natural gas', and 'Other mining', over the period 2000-2016.

We start the empirical analysis with a traditional gravity specification that includes the standard gravity covariates from the related literature (e.g., bilateral distance, regional trade agreements, etc.). This analysis demonstrates that the traditional gravity model is well suited to study trade flows in mining. Furthermore, it reveals that the estimates of the effects of bilateral policy variables, including sanctions, are possibly biased due to endogeneity. Therefore, we implement the methods of Baier and Bergstrand (2007) to account for edogeneity of bilateral trade policies. Additionally, we allow for differential effects of complete vs. partial trade sanctions. Our estimates reveal that, on average, complete trade sanctions have led to a 44 percent decrease in bilateral mining trade between the sanctioning and sanctioned countries. Moreover, we find that complete trade sanctions have been effective in reducing trade in individual mining industries (e.g., in 'Coal' and in 'Oil').[2]

Interestingly, our estimates suggest that, on average, partial trade sanctions do not affect mining trade. This result (which is also robust across the individual mining industries) seems surprising because some of the most prominent sanctions that affected the mining sector (such as the sanctions on Russia and Iran) were in fact partial. To explain this puzzle,

[2]For expositional purposes, and with the risk to abuse terminology, we will use 'Oil' industry to refer to the 'Extraction crude petroleum and natural gas' industry.

we estimate the impact of sanctions on Russia and Iran on trade in mineral products. In addition to demonstrating that the insignificant average estimate of the impact of partial trade sanctions on mining trade is masking very significant effects of individual sanctions, the focus on specific sanction episodes has two advantages from a methodological perspective. First, it demonstrates that the gravity equation can be used to study not only the average effects of sanctions, but also the impact of individual sanctions. In addition, this analysis enables us to study a number of heterogeneous effects of sanctions.

We find that the sanctions on Russia and Iran were effective in reducing the oil exports of these countries to the sanctioning states, after controlling for changes in total oil exports of the sanctioned states, total oil imports of the sanctioning states, global trends in the production, consumption, and prices of oil, and a number of other importer, exporter, and global characteristics. As it turns out, our focus on each of these sanctions unveils potentially important insights, from methodological and policy perspectives. For example, our estimates of the impact of the sanction on Russia reveal that the average impact on Russia's trade with the sanctioning countries were negative and statistically significant. However, consistent with our expectations, the negative effects of the sanction have been disproportionately larger for trade between Russia and the European Union (EU) than for trade between Russia and the other sanctioning states (e.g., Australia and Japan). Finally, we show that the impact of the sanction was asymmetric, with significantly stronger effects on EU exports to Russia. This is consistent with the findings of Felbermayr et al. (2020a) that export sanctions are enforced more strictly as compared to import sanctions. EU's dependence on Russia's oil is another possible explanation for the smaller (but still large) decrease in Russia's oil exports to the EU.

The analysis of the impact of the 2006 sanction on Iran offers two interesting insights. First, we find that the sanction resulted in a relative increase in Iran's oil exports to the sanctioning states. The explanation for this seemingly puzzling result is that, initially, the sanctions on Iran did not apply to Iran's oil exports. Thus, faced with sanctions affecting trade in other sectors, Iran increased its oil exports in order to compensate for its losses. The positive estimates we obtain are also interesting from the perspective of the extra-territorial impact of sanctions. For example, the increase in Iran's oil exports is consistent with (and may explain) the US's frustration and persistent efforts to punish companies and countries that traded with Iran during the sanction period. Second, when we explicitly allow for separate effects of the complete oil embargo on Iran (which was imposed by the EU in 2012), we obtain a very large, negative, and statistically significant estimate of the impact of the Iran sanction. From an estimation and methodological perspective, the implication of this result is that the average estimates of the impact of sanctions could be quite misleading and could mask the presence of important heterogeneous effects.

The analysis in this paper enables us to draw the following conclusions. First, from a methodological perspective, the gravity equation is well suited to model bilateral trade in mining. Second, our methods are flexible enough to allow, not only for the estimation of the average effects of sanctions, but also of their heterogeneous effects across various dimensions. Third, on average, the complete trade sanctions in our sample have led to about 44 percent lower trade between sanctioned and sanctioning countries. Fourth, the sanctions on Russia and Iran resulted in lower oil exports for these countries. However, fifth, the effects of these sanctions were heterogeneous depending on the sanctioning and sanctioned states, the direction of trade flows, and the stringency of the sanctions. Therefore, our analysis suggests that the impact of sanctions should be studied in a context of the bilateral relationship between the sanctioning and sanctioned countries, especially their trade relationship, while also taking into account the stringency of sanctions.

While the literature on sanctions is very large, spanning across political science and economics,[3] the studies that focus on the impact of sanctions on the energy and mining

[3] Without any attempt to offer an exhaustive review of the sanctions literature, the following are just few very recent examples of academic papers that study sanctions, Ahn and Ludema (2020), Attia et al. (2020), Besedeš et al. (2020), Crozet et al. (2020), Hufbauer and Jung (2020), Joshi and Mahmud (2020), Miromanova (2020), Morgan and Kobayashi (2020), and Weber and Schneider (2020).

industries, to which our work is most closely related, are few and can be classified into three categories. The first group includes descriptive analysis and case studies on mining/oil sanctions that abstract from the use of theoretical and econometric methods. Brown (2020) is a recent example of a thorough and insightful descriptive policy report on the oil market effects due to the US economic sanctions on Iran, Russia, and Venezuela. Other informative recent Congressional Research Service reports include Welt et al. (2020), for the impact of the sanctions on Russia, and Katzman (2020), for the impact of the sanctions on Iran. Our contributions in relation to this literature can be summarized as follows: (i) our econometric treatment of the effects of sanctions enables us to isolate the impact of sanctions from other potentially confounding effects; and (ii) the structural model we employ can be used to link the impact of sanctions to a number of economic outcomes which can, in turn, be used to perform 'ex-ante' and 'ex-post' analysis of the effects of sanctions.

The second group of related papers studies the effects of mining/oil sanctions on trade rely on econometric analysis and, more specifically, on the gravity model of trade. However, none of the academic papers we were able to identify and review implemented the latest developments in the structural gravity literature, thereby casting doubt on their findings.[4] Our departure from this literature is that our identification of the effects of sanctions across various dimensions relies on the latest econometric methods.

The third strand of the literature is related to (e.g. Felbermayr et al., 2020a), which introduces the *Global Sanctions Database* and implements the latest structural gravity estimation techniques to test the new sanctions database with aggregate trade. The primary difference between this literature and our contribution is that here our focus in on the mining and energy industries.

[4]For example, extending on the original work of Hufbauer and Oegg (2003) and Hufbauer et al. (2007), who applied an intuitive/a-theoretical version of the gravity model to study the effects of sanctions, most of the current literature still relies on the OLS estimator, which has been shown to be inconsistent, cf. Santos Silva and Tenreyro (2006), and does not account properly for the structural gravity multilateral resistance terms, which may lead to significant biases in the estimates of the impact of sanctions, cf. Baldwin and Taglioni (2006).

The rest of the paper is organized as follows. Section 2 sets up the estimating equation and summarizes the best practices for gravity estimations. Section 3 describes the data and data sources. Section 4 presents our main findings. Section 5 concludes with a summary of our findings and with directions for future work.

2 Estimating the Impact of Sanctions on Mining Trade

On the basis of the latest developments in the gravity literature, we synthesize insights from recent contributions that aim to assess the impact of sanctions on trade flows in order to estimate the impact of economic sanctions on international trade in mining. We rely on the gravity equation for the following reasons. First, due to its intuitive appeal and remarkable empirical success, the gravity equation has served as the workhorse model in empirical trade and has been standardly employed to quantify the effects of numerous policies (including sanctions) on international trade. Second, because the gravity equation has solid theoretical foundations, it guides our estimation approach and enables us – due to the theoretical sectoral separability of the model (c.f., Anderson and van Wincoop, 2004, and Costinot, Donaldson, and Komunjer, 2012) – to perform individual sector analysis in mining.[5] Finally, even though this is beyond the scope of this paper, the gravity equation we estimate in this paper for the mining sector belongs to a structural general equilibrium (GE) gravity system that can be used to translate the partial equilibrium estimates obtained here into GE effects on trade

[5]From a theoretical perspective, and as famously demonstrated by Arkolakis et al. (2012), equation (1) represents a very wide class of alternative theoretical micro-foundations. Anderson (1979) is the first to derive a structural gravity model of trade under the assumptions that traded goods are differentiated by place of origin (Armington, 1969) and consumer preferences are homothetic, identical across countries, and approximated by a CES utility function. Since then, the gravity equation has been derived from many alternative micro-foundations, including: monopolistic competition (Krugman (1979)); Heckscher-Ohlin foundations (Bergstrand (1985)); the Ricardian model (Eaton and Kortum (2002)); a sectoral level with a demand-side perspective (Anderson and van Wincoop (2004)); heterogeneous firms (Chaney (2008)); a sectoral level with a supply-side perspective (Costinot et al. (2012)); with country-specific dynamics via asset accumulation (Anderson et al. (2020)); with input-output linkages (Caliendo and Parro (2015)); and with bilateral dynamics (Anderson and Yotov (2020)). We refer the reader to Anderson (2011), Arkolakis et al. (2012), Costinot and Rodríguez-Clare (2014), Head and Mayer (2014), and Yotov et al. (2016) for illuminating surveys of the theoretical gravity literature.

and welfare, and to study the impact of sanctions (or any other country-specific or bilateral policies) on national and world prices.

We start by setting up our estimating equation. We then proceed to describe its components and key traits, and to explain the motivation behind each of them:[6]

$$X_{ij,t}^{k}=\exp[\pi_{i,t}^{k}+\chi_{j,t}^{k}+\mu_{ij}^{k}+\sum_{t}\alpha_{t}^{k}BRDR_{ij,t}+GRAV_{ij,t}\beta^{S}+SANCT_{ij,t}\gamma^{S}]\times\epsilon_{ij,t}^{k}. \quad (1)$$

$X_{ij,t}^{k}$ denotes nominal trade flows in mining industry k (e.g., 'mining of hard coal' or 'extraction crude petroleum and natural gas') from exporter i to importer j at time t. Due to the separability property of the structural gravity model, equation (1) can be estimated separately at any desired level of aggregation (e.g., at the product, industry, sector, and/or aggregate levels).[7] Our aim is to estimate the model by taking advantage of all available data and pooling the data across the five mining industries.[8] We prefer to utilize all industry data and pool the five industries into a single estimating sample because this approach increases the degrees of freedom and improves estimation efficiency.[9] We also obtain individual-industry estimates.

Following the recommendations of Yotov et al. (2016) for theory-consistent gravity estimations and taking advantage of one of the key dimensions of the ITPD-E, $X_{ij,t}^{k}$ includes internal trade flows (i.e., domestic sales). The inclusion of domestic trade flows in gravity estimation is consistent with any theoretical gravity model. Additionally, it generates im-

[6]We refer the reader to Baldwin and Taglioni (2006), Head and Mayer (2014) and Yotov et al. (2016) for surveys of the empirical gravity literature, and to Felbermayr et al. (2020a,b) for recent applications of the gravity model to study the effects of sanctions on trade.

[7]See Anderson and van Wincoop (2004) for a derivation of a sectoral gravity model from a demand-side perspective; Costinot et al. (2012) for a derivation of sectoral gravity model from a supply-side perspective; and Yotov et al. (2016) for a demonstration that the demand-side and supply-side sectoral gravity models are identical from an estimation point of view and for a discussion on the challenges and best practices for estimating sectoral/disaggregated gravity models.

[8]Alternatively, we could: (i) aggregate the data prior to performing the estimations by summing up the trade flows by pair and year across the five industries we consider; or (ii) we could estimate the model for each individual industry.

[9]This is particularly beneficial for our estimates of the impact of the sanctions on Russia, which were imposed in 2014 (i.e., only two years prior to the end of our sample).

portant benefits for the estimation of the effects of various policies. For example, Dai et al. (2014) demonstrate that the effects of FTAs are biased downward when gravity is estimated without domestic trade flows. The explanation for this result is that much of the additional trade between FTA members is actually due to domestic trade diversion. The intuition for the importance of using domestic trade flows when estimating the effects of sanctions is similar. When one county imposes sanctions, the sanctioned county will no longer be able to export to the sanctioning country. As a result, the sanctioned country will divert a fraction of its trade to third countries. Moreover, a significant fraction of its trade flows will be re-directed to its domestic market.

$X^k_{ij,t}$ enters (1) in levels because we estimate our specifications with the multiplicative Poisson Pseudo Maximum Likelihood (PPML) estimator. As famously argued by Santos Silva and Tenreyro (2006, 2011), the traditional OLS gravity estimates are biased due to the presence of heteroskedasticity in the data on trade flows. These authors also offer robust evidence for the ability of the PPML estimator to address the heteroskedasticity issue effectively. In addition to handling heteroskedasticity, the PPML estimator takes into account the information contained in the zero trade flows, because the corresponding estimation equation is multiplicative. This is potentially important in our case because our disaggregated mining sample contain a significant number of zeros.[10]

Equation (1) includes four sets of fixed effects. We include exporter-industry-time ($\pi^k_{i,t}$) and importer-industry-time ($\chi^k_{j,t}$) fixed effects to control for the structural multilateral resistances of Anderson and van Wincoop (2003), which are of dimension exporter-industry-time and importer-industry-time, respectively. Naturally, these fixed effects also control for any other exporter-industry-time and importer-industry-time determinants of trade flows (e.g., country-industry-specific productivity, size, etc.) which may vary over time. These fixed effects also control for any global trends that, for example, may affect sectoral and aggregate

[10]We perform our estimations in Stata, where we utilize the command *ppmlhdfe*, due to Correia et al. (2020), which is specifically designed to handle PPML estimations with high-dimensional fixed effects.

production and consumption.[11] As discussed above, we will estimate equation (1) by pulling together data across the five mining industries and by imposing common coefficient constraints on the policy variables at the aggregate sectoral level. Guided by theory, however, we will always employ exporter-industry-time and importer-industry-time fixed effects at the most disaggregated (industry) level for which data are available (i.e., the exporter-industry-time and the importer-industry-time fixed effects will be defined for each of the five mining industries for which data are available).

We also employ a set of country-pair-sector fixed effects, μ_{ij}^{k}, which, as argued convincingly by Baier and Bergstrand (2007), mitigate endogeneity concerns with respect to our key policy variables of interest and allow the country-pair-sector fixed effects to absorb all time-invariant bilateral determinants of trade flows at the product level. This is important because, as demonstrated by Egger and Nigai (2015) and Agnosteva et al. (2019), the standard gravity proxies for trade costs (e.g., the log of bilateral distance, etc.) may occasionally fail to capture all time-invariant bilateral trade costs.

Following Baier et al. (2019), we allow for the country-pair-product fixed effects to be directional (i.e., to depend on the direction of trade flows). The use of directional pair fixed effects has at least three advantages: (i) it enables us to control for the presence of asymmetric trade costs; (ii) it is consistent with the fact that many of the sanctions in our database are directional (i.e., sanctions on imports vs. sanction on exports); and (iii) the use of asymmetric effects is 'required' from en econometric perspective in some of our specifications below including, for example, our estimation of the impact of sanctions on trade flows as a function of their direction (e.g., from Russia to France vs. from France to Russia). It is also important to note that, due to the use of country-pair fixed effects, our estimates capture only the impact of the sanctions that were imposed or terminated during

[11]To see this point note that if we were to include time or industry-time fixed effects, then these effects would have been perfectly collinear with and absorbed by the more detailed exporter-industry-time and importer-industry-time that are present in all of our specifications.

the period of investigation (i.e., between 2000 and 2016).[12]

The next two sets of variables in equation (1) are designed to capture common globalization trends and the impact of a series of standard determinants of trade flows. Following Bergstrand et al. (2015), $BRDR_{ij,t}$ denotes a set of time-varying bilateral border fixed effects, which take a value of one for international trade and are equal to zero for domestic trade for each year t. The border dummies are used to control for sector-specific globalization trends. For example, these dummy variables control for improvements in technology, communication, transportation, etc. trends that affect the international (relative to internal) trade of all countries in a given sector. Also note that, by construction, the sum of the sectoral border dummies will be a common border dummy across all sectors, which will control for any common globalization trends. In other words, for each year, the sector-specific border dummies will absorb and be perfectly collinear with a common border dummy. Finally, we remind the reader that the exporter-sector-time and the importer-sector-time fixed effects absorb and control for any country-specific characteristics and trends.

The vector $GRAV_{ij,t}$ in equation (1) includes standard time-invariant gravity covariates such as the logarithm of bilateral distance ($DIST_{ij}$), indicator variables for colonial relationships ($CLNY_{ij}$), common official language ($LANG_{ij}$), and common/contiguous borders ($CNTG_{ij}$). Our main specifications do not include these covariates because they are absorbed by the pair fixed effects. However, we employ the standard gravity variables in our first specification as a benchmark and to establish the representativeness of our estimating sample. In addition to controlling for all time-invariant determinants of trade, we add to our model several time-varying policy covariates including: a dummy variable to account for the presence of regional trade agreements ($RTA_{ij,t}$), which takes a value of one if there is an RTA between countries i and j at time t, and is equal to zero otherwise; and an indicator variable for membership in the World Trade Organization ($WTO_{ij,t}$).

Superscript S on the coefficients on the standard gravity and policy variables in equation

[12] We offer additional details on the sanctions in our estimating sample in Section 3.

(1) stands for 'S'ector and is used to capture the fact that the estimates of the coefficients on these variables are constrained to be common across the five industries within the broader sector category for mining. Importantly, and as already discussed earlier, even though we constrain the estimates on the gravity and policy variables to be common across the five mining industries, we always employ the most disaggregated industry dimension of the data along with the corresponding theory-consistent fixed effects. In other words, our specifications use underlying data and structurally-motivated fixed effects at the level of the five disaggregated mining industries, but we constrain the coefficient estimates to the aggregate mining level.

Most important for our purposes, $SANCT_{ij,t}$ is a vector of sanction variables that are of central importance to the analysis. Given the use of exporter-time and importer-time fixed effects, the estimates of each of the variables in $SANCT_{ij,t}$ would measure the effect of sanctions on bilateral trade between the sanctioning country and the sanctioned state. In order to showcase the flexibility of our methods and demonstrate the importance of properly capturing the heterogeneous impact of sanctions on mining trade, in the estimation analysis we start with a baseline of sanction variables and then gradually decompose them across the key dimensions of interest to us. Specifically, initially, $SANCT_{ij,t}$ is a single indicator variable that equals one if there is a trade sanction of any sort between countries i and j at time t, and equals zero otherwise. Then, we allow for differential effects of trade sanctions by distinguishing between complete vs. partial sanctions. Lastly, we zoom in on the impact of the sanctions on Russia and on Iran by obtaining a series of heterogeneous estimates across sanctioned countries and depending on the direction of trade. We motivate and describe each step of decomposing vector $SANCT_{ij,t}$ in Section 4.

To obtain our main estimates we use consecutive-year data. Cheng and Wall (2005) remark that econometric specifications with fixed effects, such as the gravity model employed here, are *"sometimes criticized when applied to data pooled over consecutive years on the grounds that dependent and independent variables cannot fully adjust in a single year's time."*

(Footnote 8, p. 52, Cheng and Wall, 2005). Therefore, they recommend the use of interval data instead of data over consecutive years for gravity estimations. Many papers follow this recommendation and, to avoid the Cheng-and-Wall critique, they estimate gravity with interval data.[13] More recently, however, Egger et al. (2020) argue that, in addition to improving estimation efficiency and avoiding arbitrary dropping of observations, the use of pooled/consecutive-year data in fact improves our ability to capture the adjustment of trade flows in response to trade policy changes.

The logic in Egger et al. (2020) regarding estimation efficiency and the random drop in observations is especially important to our analysis of the impact of the sanctions on Russia. This is so because in this case, given the timing of the sanctions and our data coverage, we would have lost fifty percent of our observations even if we only used two-year intervals (which would also imply that our estimation of the impact of the Russian sanctions would need to be based on data for one year only). Therefore, we follow Egger et al. (2020) in using consecutive-year data to obtain our main results. Finally, we note that, given the rich structure of fixed effects in each of our specifications, we believe it is safe to assume that the error term $\epsilon_{ij,t}$ is just noise. The standard errors in all specifications will be clustered by country-pair.

3 Data: Description and Sources

We employ two novel datasets to perform our empirical analysis. The data on trade flows come from the inaugural 2020 edition of the International Trade and Production Database for Estimation (ITPD-E), which is described in Section 3.1. The data on sanctions come from the inaugural 2020 edition of the Global Sanctions Data Base (GSDB), which is described in Section 3.2. We also employ a series of other variables, which are described in Section

[13]For example, Trefler (2004) also criticizes trade estimations with samples that are pooled over consecutive years and he uses 3-year intervals. Cheng and Wall (2005) and Baier and Bergstrand (2007) use 5-year intervals, while Olivero and Yotov (2012) experiment with 3- and 5-year interval data.

3.3. In combination, the different data sources allowed us to construct an unbalanced panel estimating sample covering all trade sanctions and bilateral trade in five mining sectors (i.e., Mining of hard coal, Mining of lignite, Extraction crude petroleum and natural gas, Mining of iron ores, and Other mining) over the period 2000-2016.

3.1 The International Trade and Production Database

This section summarizes the key features of the International Trade and Production Database for Estimation (ITPD-E), which we employ for our dependent variable. ITPD-E is developed by Borchert et al. (2020b) and hosted by the US International Trade Commission at https://www.usitc.gov/data/gravity/itpde.htm. ITPD-E covers international trade data as well as consistently constructed domestic sales for the period 2000 to 2016 for 243 countries and 170 industries. Most importantly, the ITPD-E includes five mining industries, which we use for our analysis.[14]

The original source for international trade data in mining is the UN Commodity Trade Statistics Database (COMTRADE). The production data are from the UNIDO United Nations Mining and Utilities Statistics Database (MINSTAT) Database. Consistent with gravity theory, reported import flows are used as the main variable, and mirror exports from partner countries are used to fill missing import values. The production data are from the UNIDO United Nations Mining and Utilities Statistics Database (MINSTAT) Database, and domestic sales are calculated as the difference between the values of total (gross value) production and total exports.

The five mining sectors in ITPD-E are "Mining of hard coal" (sector 27 in ITPD-E); "Mining of lignite" (sector 28 in ITPD-E); "Extraction crude petroleum and natural gas" (sector 29 in ITPD-E); "Mining of iron ores" (sector 30 in ITPD-E); and "Other mining and quarrying" (sector 31 in ITPD-E). Figure 1 plots the average trade (in millions of current US$) for each of these sectors during the period 2000-2016. Several features are worth noting

[14]See Borchert et al. (2020a) for a first test of the usefulness of the database for gravity estimations.

in this figure. First, the sector “Crude petroleum and natural gas” is by far the largest in terms of average trade. Second, there are significant fluctuations in the value of trade in mining industries. There was a significant growth in the value of trade until 2008 in all industries. The 2008 financial crises is also visible in the mining data, most clearly for “Crude petroleum and natural gas” and “Mining of iron ores”. While we observe a drop in the average trade for all mining industries towards the end of our period of investigation, we observe a very pronounced drop for “Crude petroleum and natural gas”.

The drop in the exports of “Crude petroleum and natural gas” after 2012 coincides with the imposition of economic sanctions on the large exporters of oil (Russia and Iran) during the same period. Therefore, and in order to motivate our econometric analysis, we zoom in on the oil trades of Russia and Iran in Figure 2. Overall, we see a similar pattern for both countries’ exports of oil – both Russia and Iran hardly import any oil. Two notable differences in the evolution of these countries’ exports are (i) the sharp fall in Iran’s oil exports around 2011-2012, and (ii) the sharp reduction in the value of Russia’s oil exports in 2014. Importantly, the fall in Iran’s oil exports coincides with the 2012 EU oil embargo on this country, while the decrease in Russia’s oil exports coincides with the sanctions imposed on this country due to the Crimean crisis.

In order to obtain more intuition on the drivers of the changes in the oil exports of Russia and Iran during this period, we use the data from the U.S. Energy Information Administration (EIA) on the exports of these countries in real terms, i.e. millions of barrels of oil per day (Mb/d). This information is plotted in Figures 3 and 4. In Figure 3 one can see that while Iran’s real exports do not change much around 2006 (though there is a small decline around 2007-2009), they fall dramatically around 2012, thereby reinforcing the possibility that this country’s oil exports were significantly (and negatively) affected by sanctions. Figure 4, however, reveals that Russian oil exports actually increased in real terms after 2014, suggesting that the decrease in value terms, which we saw in Figure 2 in the case of Russia, were driven by fluctuations in the price of oil. The econometric analysis in Section 4.2 would enable us to isolate the impact of the fluctuations in world oil prices, so we can test whether the links between sanctions and the oil exports of Russia and Iran are indeed causal and, if so, to quantify the contributions of these two sanction cases.

A comparison of the scaling of the y-axis of Figures 1 and 2 suggests that Russia and Iran are among the top exporters of oil in the world. Table 1 confirms this point by highlighting the top 10 exporters of oil in 2016, in term of total exports (in million US$). Saudi Arabia is on top of the list with 104 billion US$, followed by Russia with 94 billion US$. Iran is on the 9th place with 29 billion US$. In order to validate the magnitudes, we compare our numbers and rankings with figures from `worldstopexports.com` and `Observatory of Economic Complexity (OEC)`.[15] The similarity of these figures gives us confidence in using the mining data from ITPD-E for our analysis.

3.2 The Global Sanctions Database

The Global Sanctions Data Base (GSDB) was created by Felbermayr et al. (2020a) and covers all publicly traceable sanctions in the world over the period 1950-2016. Specifically, the GSDB includes 729 sanction cases, which are classified along the following three dimensions: their objective(s), their rates of success, and their type. The GSDB distinguishes between nine categories of sanctions based on their objectives: to change policy; to destabilize a regime; to resolve territorial conflict; to prevent war; to end war; to prevent the rise of terrorist groups; to end human rights violations; to restore democracy; and other objectives. Depending on how successful sanctions are in achieving their objectives, the GSDB classifies sanctions in several categories, ranging from complete failure to complete success. Finally, and most important for our purposes, the GSDB distinguishes among six types of sanctions based on the targeted activity: trade, financial, arms, military assistance, travel, and other sanctions. The GSDB also classifies sanctions as partial (those that apply only to specific

[15] http://www.worldstopexports.com/worlds-top-oil-exports-country/ and https://oec.world/en/profile/hs92/crude-petroleum.

goods and/or particular sector(s) of trade) or complete (those that apply to all sectors); and as export sanctions, import sanctions, or bilateral sanctions, depending on the direction of trade flows. At the same time, similar to existing datasets on free trade agreements, the GSDB does not have an industry dimension, meaning that it does not specify which industries the sanctions apply to.[16] For additional details on the GSDB we refer the reader to Felbermayr et al. (2020a) and Felbermayr et al. (2020b).[17]

Motivated by our objective to study mining trade, we will focus on trade sanctions and will capitalize on the dimensionality of the GSDB with respect to this sanction type. Due to the fact that our estimating sample covers the period 2000-2016 (as predetermined by the availability of the trade data in the ITPD-E), our analysis will include a total of 116 trade sanction cases, which were either initiated or terminated during the period 2000-2016. All the cases used in the estimations are listed in Table 2, which reports the first and last year of each sanction (in columns 2 and 3, respectively), the sanctioned and sanctioning countries (in columns 4 and 5, respectively), and the type of trade sanction considered (in column 6). As discussed in the previous section, we will fully control for (but will not be able to use for identification purposes) the sanctions that are active throughout the whole period of investigation (e.g., the US sanction on Cuba or the Turkey sanction on Armenia, which started in 1962 and 1993, respectively, and were still in place during the last year of our sample). The effects of these sanctions will be absorbed by the country-pair fixed effects in our specifications. Once again, we will control for these sanctions but we will not use them for identification. (This explains why these sanctions are not listed in Table 2.)

To obtain a better view of the importance of trade sanctions during the period of investigation and to motivate our empirical analysis and econometric specifications, we also analyze the evolution (over time) of trade sanctions by type (i.e., partial vs. complete) across the

[16]Based on anecdotal evidence, some sanctions are indeed directed at specific sectors. Still, this type of industry-targeted cases are rare. Nevertheless, our econometric analysis will enable us to capture the sector-specific effects of sanctions, and it will reveal that these effects may be quite heterogeneous.

[17]The home page of the GSDB is https://www.globalsanctionsdatabase.com. The GSDB is a free and can be requested by sending an e-mail to GSDB@drexel.edu.

country pairs in our sample. Table 3 reports the number of country-pairs that were affected by trade sanctions in each year during the period 2000 and 2016. Column (2) lists the total number of country pairs affected by trade sanctions regardless of type, while columns (3) and (4) decompose the numbers from column (3) into complete vs. partial sanctions, respectively. Figure 5 depicts the data from Table 3. Several observations from the table stand out.

First, the total number of pairs affected by trade sanctions has doubled between 2000 and 2014. The explanation of this trend is not an increase in the number of trade sanctions, but rather the fact that more trade sanctions were imposed by the United Nations and the European Union. Importantly, the aggregate increase is exclusively due to the increase in partial trade sanctions. In fact, the descriptive statistics in Table 3 and Figure 5 reveal that, after a dramatic fall in 2003, the number of complete trade sanctions remained low and steady during the period of investigation. The reason for this decrease in the number of country pairs that were part of complete trade sanctions was the lifting of the UN sanctions on Iraq in 2003.

In contrast to the decrease in the number of pairs affected by complete trade sanctions, the number of pairs involved in partial trade sanctions almost tripled between 2000 and 2014. Consistent with the proliferation of 'smart' (i.e., financial and travel) sanctions that target specific individuals and/or institutions, we think the increase in the use of partial over complete trade sanctions is due to the sanctioning countries' objective to inflict pain on specific sectors in the target country rather than the economy as a whole. Figure 5 also unveils several patterns in the evolution over time of partial trade sanctions.

We first see a large increase in the number of pairs affected by partial trade sanctions in 2006. This is due to the UN sanctions on Iran and on North Korea. Owing to the importance of oil exports to Iran and the specific nature of the sanctions imposed on it, we plan to offer a specific analysis of the impact of these sanctions.[18] The second increase in the number

[18]Initially, the sanctions on Iran did not affect Iranian exports of oil. However, in 2012, the EU imposed a complete oil embargo on Iran. We will capitalize on this dramatic shift in policy in order to demonstrate the flexibility of our estimation methods and also to generate some interesting policy insights.

of affected pairs is in 2011. This increase is due to the UN sanctions on Eritrea and the EU sanctions on Libya, Syria and Belarus. The next sharp increase in affected pairs is in 2014. The corresponding spike in Figure 5 is exclusively due to the sanctions on Russia and Ukraine in relation to the Crimean crisis. The fact that Russia is a key supplier of crude petroleum and natural gas to the EU together with the ongoing interest in this effects of this sanction motivated us to devote special attention to the sanctions on Russia in our empirical analysis. Finally, in 2015, we observe a small decrease in the number of pairs affected by partial trade sanctions due to the lifting of the EU sanction on Fiji.

3.3 Other Data and Variables

In addition to the key data on sanctions and trade flows, we also employ a number of variables that are standardly used in the gravity literature, including the logarithm of bilateral distance (DIST) and indicator variables for colonial relationships (CLNY), common language (LANG), common borders (CNTG), membership in the World Trade Organization (WTO), and participation in regional trade agreements (RTAs). The data on RTAs come from the Regional Trade Agreements Database, which is developed by Egger and Larch (2008) and is freely available for downloading at https://www.ewf.uni-bayreuth.de/de/forschung/RTA-daten/index.html. Data on all other standard gravity variables are from the Dynamic Gravity Database of the US International Trade Commission (c.f., Gurevich and Herman (2018)), which is downloadable for free at https://catalog.data.gov/dataset/dynamic-gravity-dataset-1948-2016.

4 Estimation Results and Analysis

This section presents our main findings. In the spirit on the voluminous empirical trade literature that estimates the effects of regional trade agreements, Section 4.1 offers an analysis of the average impact of trade sanctions on mining trade.[19] While the average estimates we obtain are informative, the effects of sanctions are often analyzed on a case by case basis. Section 4.2 demonstrates that our methods can also be used to quantify the impact of individual sanction episodes (e.g., the sanctions on Russia and Iran) and to allow for heterogeneous sanction effects across sanctioned countries, depending on stringency and the direction of trade flows within individual sanction cases.

4.1 Do Trade Sanctions Impede Mining Trade?

We start the empirical analysis with a specification that includes the standard set of gravity variables that have been used in thousands of regressions. Our results appear in column (1) of Table 4. The estimates on all time-invariant gravity variables are consistent with those from the literature. Specifically, without going into detail, we note that, according to our results, distance (DIST) is a significant impediment to international trade in mining, while colonial ties (CLNY) and the presence of contiguous borders (CNTG) promote bilateral mining trade. Notably, we obtain a relatively large estimate of the impact of distance (usually gravity models deliver distance estimates of -0.8 to -1). High transportation costs for mining are the natural explanation of this finding. Consistent with the literature, the estimate on common official language (LANG) is positive, but it is not statistically significant. In terms of magnitude, the estimates of the time-invariant gravity variables from column (1) are comparable to those from the gravity meta analysis of Head and Mayer (2014), thus indicating that the gravity model works well for trade in mining.

Turning to the policy variables from column (1), we see that the estimates of the effects of WTO and RTA are large, positive, and statistically significant; therefore, WTO membership and the formation of RTAs have promoted international trade in mining. Interestingly, however, the estimate of the impact of trade sanctions ($TRADE\_SANCT$) is not statistically

[19] In fact, the title of Section 4.1 was inspired by the seminal work of Baier and Bergstrand (2007) titled "Do Free Trade Agreements Actually Increase Members' International Trade?".

significant; that is, trade sanctions appear not to have affected international trade in mining. An important deficiency in the specification in column (1) is that it does not account for possible endogeneity of the bilateral policy variables in our econometric model. To address this issue, we rely on the methods of Baier and Bergstrand (2007), who demonstrate that the consideration of country-pair fixed effects in gravity regressions successfully account for endogeneity of free trade agreements. As discussed earlier, the pair fixed effects will also completely control for all time-invariant bilateral trade costs (c.f., Egger and Nigai (2015) and Agnosteva et al. (2019)).

Taking into account the industry dimension of our econometric model and allowing for asymmetric trade costs, the estimates in column (2) of Table 4 are obtained with directional country-industry-pair fixed effects. The estimate on $TRADE\_SANCT$ is now negative, but still not statistically significant. In fact, none of the estimates on the three policy variables in column (2) are statistically significant. We offer three possible explanations for the differences between the estimates in columns (1) and (2). First, the WTO and RTA effects in column (1) could have captured the impact of old RTAs and early WTO membership. The loss of significance suggests that, while potentially important, the gains from old RTAs and early WTO membership are absorbed by the country-pair fixed effects. Second, consistent with Baier and Bergstrand (2007), the introduction of the fixed effects may have mitigated endogeneity concerns by absorbing much of the unobserved correlation between the potentially endogenous policy variables and the error term. Finally, consistent with the main argument in Baier et al. (2019) that the impact of FTAs may vary significantly across agreements, it is possible that the average policy estimates in column (2) mask significant heterogeneity. We explore this possibility next.

The estimates in column (3) distinguish between the effects of complete vs. partial trade sanctions. Our results reveal that the impact of complete trade sanctions is negative, large, and statistically significant, while the effects of partial trade sanctions are economically small and statistically insignificant. In terms of volume effects, our estimates imply that, on average, complete trade sanctions have reduced bilateral mining trade between the sender and target countries by about 44 percent ($(\exp(-0.587) - 1) \times 100$). The difference in the effectiveness of complete vs. partial sanctions is intuitive and our results confirm similar findings for aggregate trade in Felbermayr et al. (2020a). However, given that some of the most prominent sanctions in the mining sector (e.g., on Russia and Iran) are partial, we find the small and insignificant estimate on $PARTIAL\_SANCT$ puzzling. We offer an explanation for this result in the next section. Prior to that, however, we test whether the impact of trade sanctions differs across the main mining industries in our sample.

Panel B of Table 4 reports estimates for 'Mining of hard coal' (COAL), 'Extraction crude petroleum and natural gas' (OIL), and a combined category for 'Other mining' (OTHR), in columns (4), (5), and (6), respectively. Several findings stand out. First, we note that the estimates on WTO and RTA are positive and significant in the coal industry. More importantly, we see that complete trade sanctions have been effective in reducing trade in crude petroleum and natural gas and that they have been especially effective in the case of coal (for which our estimate implies a decrease of more than 90 percent in the bilateral trade between sender and target countries). The estimates of the impact of sanctions on trade in 'Other mining' are not statistically significant. A possible explanation for this result is that this sector is a combination of different mining industries (e.g., lignite, iron, etc.) and, therefore, the average estimate we obtain may be masking significant effects on the individual industries. We elaborate on this point in the next section, where we allow for the presence of heterogeneous effects of sanctions across several dimensions.

4.2 Heterogeneous Impact of Sanctions: Cases of Iran and Russia

This section presents estimates of the effects of three specific sets of sanctions: the 2014 sanctions on Russia and the 2006 and 2012 sanctions on Iran. There are several reasons to focus on these sanctions. First, the sanctions on Russia and Iran are two of the most politically charged and widely discussed sanctions in recent history. Second, mining trade, and especially trade in crude petroleum and natural gas, are major components of Russia's and Iran's overall exports. Therefore, the analysis in this section zooms in on sector 'Extraction crude petroleum and natural gas' (OIL). Finally, from a methodological perspective, this analysis demonstrates the effectiveness of our method in identifying the effects of specific sanctions and sanction episodes. Our methodology captures the fact that the impact of sanctions is heterogeneous and depends on various country-specific and bilateral geopolitical and institutional factors, as well as on changes in the implementation of sanctions, such as their stringency.

The 2006 sanctions on Iran were imposed pursuant to the UN Security Council Resolution 1737. The UN sanctions banned the supply of nuclear-related materials and technology and froze assets of key individuals and companies related to the program. Subsequent UN sanctions imposed additional asset freezes and other restrictions. At the same time, additional U.S. sanctions targeted investments in oil, gas, and exports of refined petroleum products. The sanctions also covered banking and insurance transactions, shipping, and internet-related services.

The 2014 sanctions on Russia, which were imposed by several countries, led by the United States and European Union, included a ban on the provision of technology for oil and gas exploration, a ban on provision of credits to Russian oil companies and state banks, and travel restrictions on influential Russian citizens who were close to President Putin and were involved in the annexation of Crimea. The Russian government responded with sanctions against some Canadian and American individuals and, in August 2014, with a total ban on food imports from the European Union, the United States, Norway, Canada and Australia.

Even though the 2006 sanctions on Iran and the 2014 sanctions on Russia did not restrict trade in oil or other mining products, they may still have an impact on trade in mineral products, especially on bilateral trade in mineral products with the sanctioning countries. One reason for this is that financial sanctions make settlement of trade transactions much more difficult. In extreme cases of nearly complete financial sanctions, transactions can only be settled by cash or gold, which is nearly impossible to implement when these transactions are worth billions of dollars. Similarly, sanctions on transport make it more difficult to find transport companies willing to move the cargo. By contrast, the 2012 sanctions on Iran included a complete EU ban on trade in oil. In addition, all Iranian banks identified as institutions in breach of EU sanctions were disconnected from the SWIFT, the world's hub of electronic financial transactions.

Our results are presented in Table 5. To facilitate the comparison, column (1)/panel A reproduces the estimates for the 'Extraction crude petroleum and natural gas' sector from column (5) of Table 4. The estimates in panel B focus on the sanctions on Russia. Column (2) isolates the effects of the sanction on Russia by introducing a new indicator variable, RUS_ALL, which takes the value of one for trade between Russia and the sanctioning countries during the sanction period, and equals zero otherwise.[20] Note that the effects of the world price of oil and its decline during this period are captured in the time-varying exporter and importer fixed effects since it affects all exporters and importers. The estimate on RUS_ALL is negative but still not statistically significant. We also note that the estimate on $PARTIAL\_SANCT$, which now captures the impact of all other partial sanctions except for the sanctions on Russia, becomes positive. A tentative implication of these findings, which we reinforce below, is that the average estimate of the impact of partial sanctions may be misleading.

In column (3) of Table 5, we allow for differential effects of the sanction on Russia on its trade with the European Union (RUS_EU) vs. its trade with the rest of the sanctioning countries (RUS_NOEU), including Australia, Canada, Japan, Switzerland and the United States. The motivation for this specification is that the EU does a significant amount of trade with Russia and also took a relatively strong stand against Russia in relation to the

[20]We remind the reader that the sanction on Russia was imposed by the EU, the US, Australia, Canada, Japan, Switzerland and New Zealand in 2014. Since New Zealand's sanction was not on trade, we do not account for it in our analysis. We also note that, to ease interpretation, we have subtracted the new dummy variable RUS_ALL from the other sanction variables. Thus, the estimate on RUS_ALL can be interpreted directly in levels and not as a deviation from the other sanction estimates.

Crimean crisis. Consistent with our expectations, the estimates in column (3) reveal that the estimate of the impact of the EU sanction on Russia is negative, large, and statistically significant. However, the estimate of the average impact of the sanctions on Russia from other countries is not statistically significant. These results reinforce our conclusion that the effects of sanctions can be quite heterogeneous. Note that the negative coefficient does not mean that Russian oil exports have declined after sanctions were imposed. It means that Russian oil exports to the EU relative to Russian oil exports to all destinations and relative to EU oil imports from all destinations have declined. The ability to isolate the bilateral effect of sanctions is one of the advantages of the empirical methodology we employ.

Finally, column (4) takes our analysis one step further by allowing for asymmetric effects of the sanction on Russian exports to the EU (RUS_EU) vs. EU exports to Russia (EU_RUS). The motivation for this specification is twofold. First, oil trade between Russia and the EU is highly asymmetric. Second, Felbermayr et al. (2020a) offer evidence that export sanctions are imposed more strictly as compared to import sanctions. Three results stand out from column (4). First, the impact of the sanction is asymmetric. Second, the estimate on Russia's exports to the EU is unchanged as compared to the one in the previous column. This is a reflection of the fact that Russian exports to the EU are significantly larger as compared to EU exports to Russia; that is, the estimate on RUS_EU in column (3) is almost exclusively driven by the impact of the sanction on Russia's oil exports to the EU. Third, the estimate of the impact of the sanction on EU exports to Russia is significantly larger. This is consistent with Felbermayr et al. (2020a) who find that the enforcement on export sanctions is stricter than the corresponding enforcement on import sanctions.

The estimates in panel C focus on the sanctions on Iran. While still controlling for the heterogeneous impact of the sanction on Russia, column (5) of Table 5 isolates the effects of the sanctions on Iran that were first imposed in 2006 (IRN_ALL). Surprisingly, our estimates reveal that Iran's oil exports actually increased in response to the sanctions on this country. This result seems to contrast sharply the estimates from Felbermayr et al. (2020a) who find that the average impact of the Iran sanctions on this country's overall trade was negative and economically and statistically significant. However, these two findings are not necessarily mutually exclusive. Specifically, we believe that the positive estimate obtained here reflects the fact that the 2006 sanction on Iran was not imposed on Iran's oil trade. Thus, faced with sanctions affecting trade in other sectors, Iran expanded its oil exports in order to compensate for potential losses due to reduced trade in other areas.

Similar to our analysis of the effects of the sanctions on Russia, column (6) of Table 5 allows for differential sanction effects on trade with the European Union (IRN_EU) vs. the rest of the sender countries (IRN_ALL), including many countries as part of the UN sanction on Iran. Additional motivation for the focus on trade with the EU is that the EU implemented a complete oil embargo on Iran in 2012, which we focus on later in this section. The primary finding in column (6) is that the impact of the EU sanctions on Iran was not statistically different from the average effect of the sanctions from all other countries. In both cases, our estimates are large, positive, and statistically significant. The positive estimates we obtain are also interesting from the perspective of the extra-territorial impact of sanctions. For example, the increase in Iran's oil exports may explain the frustration of the U.S. and its renewed efforts to punish companies and countries that traded with Iran during the sanction period.

We conclude the analysis of the sanction on Iran with a specification that is designed to capture the impact of the complete EU oil embargo on Iran starting in 2012 (IRN_EU_2012). The results from column (7) of Table 5 send two important messages. From a policy perspective, the large, negative and statistically significant estimate on IRN_EU_2012 reveals that the EU oil embargo on Iran was very effective in reducing Iranian oil exports to the EU. From an estimation and methodological perspective, this finding implies that the average estimates of the impact of all sanction on Iran from the previous columns could be hiding important differences in the effects of 2012 sanctions from the other sanctions on Iran. In combination, our estimates of the impact of the sanction on Iran reinforce our two main conclusions in this section: (i) The gravity methods we employ are flexible enough to allow for the estimation not only of the average effects of sanctions, but also of their heterogeneous effects across various dimensions (e.g., sectors, regions, countries, specific sanctions, stringency of sanction, etc.); (ii) a proper quantification of the economic impact of sanctions requires paying careful attentions to various country-specific and bilateral factors, which can be geopolitical and economic in nature, between sanctioning and sanctioned countries; and taking in account the stringency of sanctions.

5 Conclusion

We relied on the gravity model of trade and two new datasets to analyze the impact of sanctions on international trade in mining. From a methodological perspective, our analysis demonstrates that the gravity equation is well-suited to model bilateral trade in mining and that the related methods are flexible enough to allow for the estimation of the average effects of sanctions and their heterogeneous effects across various dimensions.

From a policy perspective, our estimates reveal that the complete trade sanctions in our sample have led to a reduction of about 44 percent in mining trade between sanctioned and sanctioning countries. Furthermore, we obtained significant estimates of the effects of sanctions on Russia and on Iran's bilateral trade and showed that the effects of these sanctions are heterogeneous depending on the identify of the sanctioning state, the direction of trade flows, and the stringency of sanctions. Overall, our analysis suggests that proper quantification of the economic impact of sanctions on mining trade requires that we consider the economic and geopolitical relationships between senders and targets; and take into account the stringency of sanctions and any changes in their institutional implementation.

The ability to quantify the direct/partial equilibrium impact of economic sanctions on international trade flows in mining, together with the significant results we obtained, open a number of opportunities for future research. For example, as established in the literature, the structural gravity model is a general equilibrium model that can be used to translate the partial equilibrium estimates from this study into general equilibrium effects on oil production and prices in the world. However, a proper account for the general equilibrium links between trade and mining requires taking into account the specific features of natural resources (e.g., depletion, substitutability, and their role as key intermediates in production), thus offering an opportunity for theoretical contributions. We believe the development of a structural estimation framework of trade and natural resources would open new avenues for research in, for example, establishing possible links between sanctions and trade diversion, environmental effects, and strategic/security concerns.

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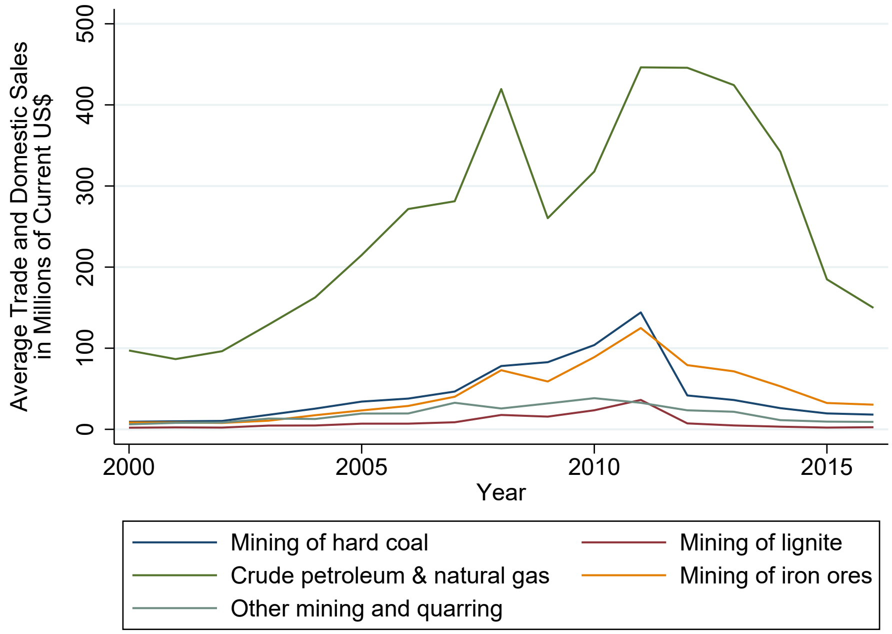
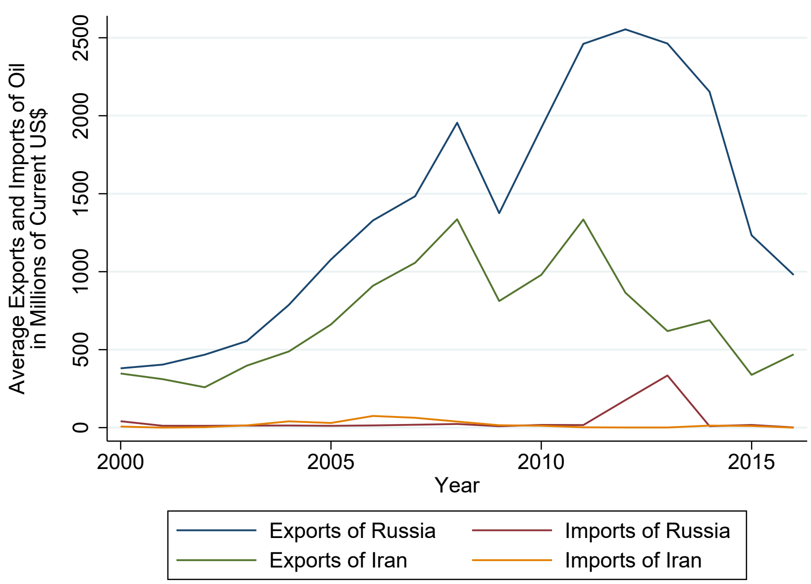
Figure 1: Evolution of World Mining Trade, 2000-2016



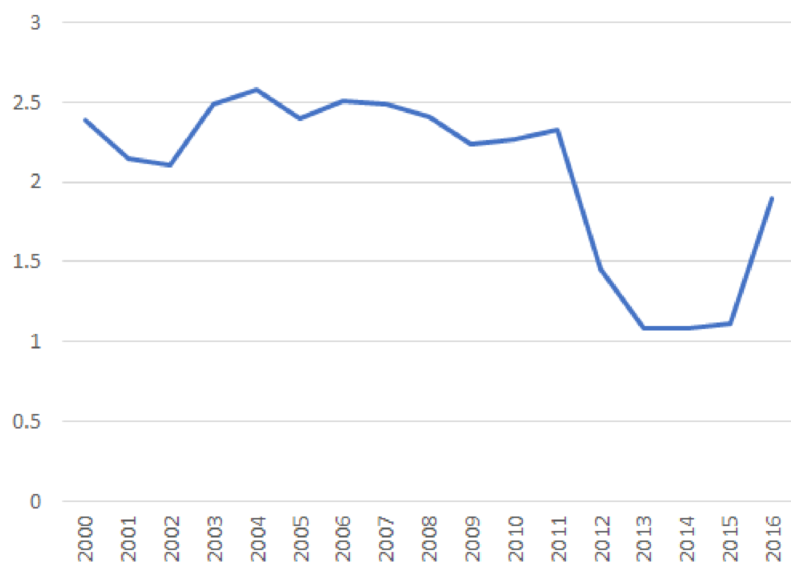
Notes: This figure shows the evolution of the average trade and domestic sales of the five mining sectors in ITPD-E for the years 2000 to 2016. See text for further details.

Figure 2: Oil Exports and Imports of Russia and Iran, 2000-2016



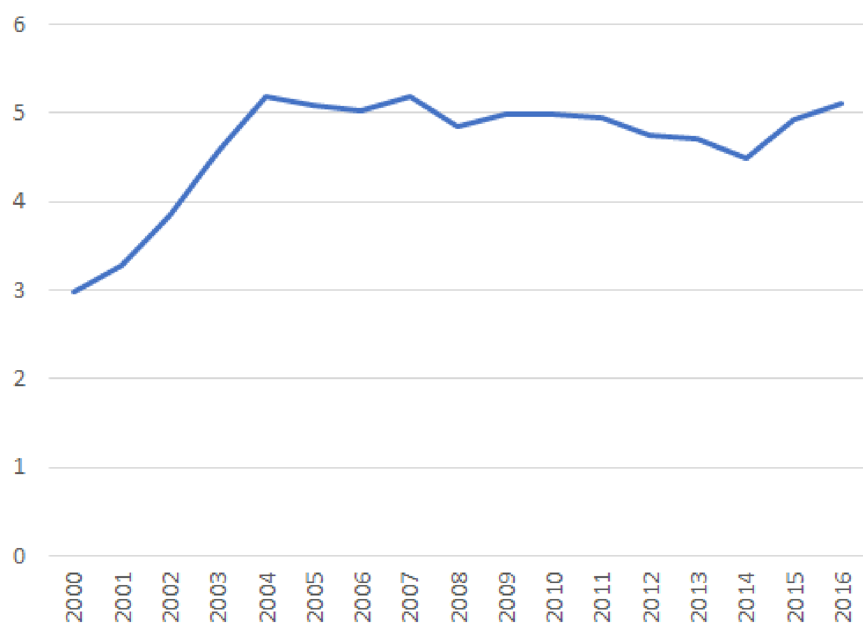
Notes: This figure shows the evolution of the average oil exports and imports of Russia and Iran over the period 2000-2016. See text for further details.

Figure 3: Oil Exports of Iran, 2000-2016, Mb/d



Notes: This figure shows the oil exports of Iran in millions of barrels per day.
Source: U.S. EIA

Figure 4: Oil Exports of Russia, 2000-2016, Mb/d



Notes: This figure shows the oil exports of Russia in millions of barrels per day.
Source: U.S. EIA

Table 1: Top 10 Oil Exporters, 2016

Country	Volume
Saudi Arabia	103795.80
Russia	94005.15
Canada	46509.64
Iraq	46060.78
United Arab Emirates	37695.42
Qatar	35919.69
Norway	32964.69
Nigeria	30518.43
Iran	28643.20
Kuwait	28593.15

Notes: This table lists the top 10 exporters of oil in the world, in column (1), and the corresponding export values (in million US$), in column (2), in the year 2016.

Table 2: Active Sanction Cases, 2000-2016

(1) Case ID	(2) Start Year	(3) End Year	(4) Target Country	(5) Sender Country	(6) Type
1	1999	2002	Afghanistan	United States	Exp.Part, Imp.Part
2	2000	2002	Afghanistan	United Nations	Exp.Part
3	2001	2002	Afghanistan	European Union(+)	Exp.Part
4	1993	2002	Angola	United Nations	Exp.Part
5	1997	2002	Angola	United Nations	Exp.Part
6	1998	2002	Angola	United Nations	Imp.Part
7	2006	2016	Belarus	Canada	Exp.Part
8	2006	2016	Belarus	United States	Exp.Part, Imp.Part
9	2011	2016	Belarus	European Union(+)	Exp.Part
10	2012	2016	Belize	United States	Exp.Part, Imp.Part
11	2005	2016	Cote d'Ivoire	European Union(+)	Exp.Part
12	2005	2014	Cote d'Ivoire	United Nations	Exp.Part, Imp.Part
13	2011	2016	Eritrea	United Nations	Imp.Part
14	2000	2003	Fiji	United Kingdom	Exp.Part
15	2007	2015	Fiji	European Union	Exp.Part
16	2006	2011	Georgia	Russia	Exp.Compl, Imp.Compl
17	2006	2013	Georgia	Russia	Imp.Part
18	2006	2013	Georgia	Russia	Imp.Part
19	2009	2014	Guinea	European Union(+)	Exp.Part
20	2010	2014	Guinea	Switzerland	Exp.Part
21	1974	2008	India	Canada	Exp.Part, Imp.Part
22	1998	2001	India	United States	Exp.Part
23	2011	2011	Indonesia	Australia	Exp.Part
24	2011	2016	Indonesia	United States	Exp.Part, Imp.Part
25	2006	2016	Iran	Japan	Imp.Part
26	2006	2016	Iran	United Nations	Exp.Part, Imp.Part
27	2008	2016	Iran	Australia	Exp.Part, Imp.Part
28	2010	2016	Iran	United Nations	Exp.Part
29	2010	2016	Iran	Canada	Exp.Part
30	2011	2016	Iran	Switzerland	Exp.Part, Imp.Part
31	2011	2016	Iran	Canada	Exp.Part
32	2012	2016	Iran	European Union	Exp.Part
33	2012	2016	Iran	Canada	Exp.Part, Imp.Part
34	2012	2016	Iran	European Union(+)	Exp.Part, Imp.Part
35	2013	2016	Iran	Canada	Exp.Compl, Imp.Compl
36	2016	2016	Iran	Switzerland	Exp.Part
37	2016	2016	Iran	Canada	Exp.Part
38	1990	2003	Iraq	European Union	Exp.Part
39	1990	2003	Iraq	United Nations	Exp.Compl, Imp.Compl
40	1991	2003	Iraq	United Nations	Exp.Compl, Imp.Compl
41	1955	2008	Korea, North	United States	Exp.Compl, Imp.Compl
42	2002	2006	Korea, North	United States	Exp.Part
43	2006	2016	Korea, North	Australia	Exp.Part, Imp.Part
44	2006	2016	Korea, North	European Union	Exp.Part
45	2006	2016	Korea, North	United Nations	Exp.Part, Imp.Part
46	2006	2016	Korea, North	Japan	Imp.Compl
47	2008	2016	Korea, North	United States	Exp.Part
48	2009	2016	Korea, North	Japan	Exp.Compl
49	2011	2016	Korea, North	Canada	Exp.Compl, Imp.Compl
50	2011	2016	Korea, North	United States	Imp.Compl
51	2001	2007	Liberia	United Nations	Imp.Part
52	2001	2016	Liberia	European Union	Imp.Part
53	2003	2006	Liberia	United Nations	Imp.Part
54	2004	2015	Liberia	United States	Exp.Part, Imp.Part
55	1978	2004	Libya	United States	Exp.Part
56	1981	2004	Libya	United States	Exp.Part
57	1982	2004	Libya	United States	Exp.Part, Imp.Part
58	1986	2004	Libya	United States	Exp.Part, Imp.Part
59	1992	2003	Libya	United Nations	Exp.Part
60	1993	2003	Libya	United Nations	Exp.Part
61	2011	2016	Libya	European Union(+)	Exp.Part
62	2011	2016	Libya	Switzerland	Exp.Part

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(1) Case ID	(2) Start Year	(3) End Year	(4) Target Country	(5) Sender Country	(6) Type
63	2011	2016	Libya	Canada	Exp.Part, Imp.Part
64	2013	2013	Mali	United States	Exp.Part, Imp.Part
65	2006	2007	Moldova	Russia	Imp.Part
66	2013	2016	Moldova	Russia	Imp.Part
67	2012	2016	Moldova	United States	Exp.Part, Imp.Part
68	2000	2003	Myanmar	European Union(+)	Exp.Part
69	2000	2006	Myanmar	Switzerland	Exp.Part
70	2003	2010	Myanmar	European Union(+)	Exp.Part
71	2003	2016	Myanmar	United States	Exp.Part
72	2006	2012	Myanmar	Switzerland	Exp.Part
73	2007	2016	Myanmar	United States	Exp.Part, Imp.Part
74	2007	2012	Myanmar	Canada	Exp.Compl, Imp.Compl
75	2008	2016	Myanmar	United States	Imp.Part
76	2010	2013	Myanmar	European Union(+)	Exp.Part, Imp.Part
77	2013	2016	Myanmar	European Union(+)	Exp.Part
78	2012	2016	Palestine	United States	Exp.Part, Imp.Part
79	2014	2016	Russia	Australia	Exp.Part
80	2014	2016	Russia	Canada	Exp.Part
81	2014	2016	Russia	United States	Exp.Part, Imp.Part
82	2014	2016	Russia	European Union	Exp.Part, Imp.Part
83	2014	2016	Russia	Switzerland	Exp.Part, Imp.Part
84	2014	2016	Russia	Japan	Imp.Part
85	1997	2003	Sierra Leone	ECOWAS	Exp.Compl, Imp.Compl
86	2000	2003	Sierra Leone	United Nations	Exp.Part
87	2001	2003	Sierra Leone	Liberia	Imp.Part
88	2009	2016	Somalia	Switzerland	Imp.Part
89	2010	2016	Somalia	United States	Imp.Part
90	2012	2016	Somalia	European Union(+)	Imp.Part
91	2012	2016	Somalia	United Nations	Imp.Part
92	2013	2016	Somalia	Switzerland	Imp.Part
93	2006	2016	Sudan	United States	Exp.Part, Imp.Part
94	2010	2011	Switzerland	Libya	Exp.Compl, Imp.Compl
95	2004	2016	Syria	United States	Exp.Part, Imp.Part
96	2011	2016	Syria	United States	Exp.Part, Imp.Part
97	2011	2012	Syria	Switzerland	Exp.Part
98	2011	2016	Syria	Australia	Exp.Part, Imp.Part
99	2011	2016	Syria	Canada	Exp.Part, Imp.Part
100	2011	2013	Syria	European Union(+)	Exp.Part, Imp.Part
101	2011	2016	Syria	League of Arab States	Exp.Part, Imp.Part
102	2012	2016	Syria	Switzerland	Exp.Part
103	2012	2016	Syria	Canada	Exp.Part
104	2013	2016	Syria	Canada	Exp.Part
105	2013	2016	Syria	European Union(+)	Exp.Part, Imp.Part
106	2014	2014	Ukraine	European Union(+)	Exp.Part
107	2014	2016	Ukraine	Canada	Exp.Part, Imp.Part
108	2014	2016	Ukraine	United States	Exp.Part, Imp.Part
109	2014	2016	Ukraine	Switzerland	Exp.Part, Imp.Part
110	2014	2016	Ukraine	European Union(+)	Exp.Part, Imp.Part
111	2014	2016	Ukraine	Japan	Imp.Part
112	2005	2009	Uzbekistan	European Union	Exp.Part
113	2015	2016	Venezuela	United States	Exp.Part, Imp.Part
114	1998	2001	Yugoslavia	European Union	Imp.Part, Exp.Part
115	2002	2016	Zimbabwe	Switzerland	Exp.Part
116	2002	2016	Zimbabwe	European Union (+)	Exp.Part

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(1) Case ID	(2) Start Year	(3) End Year	(4) Target Country	(5) Sender Country	(6) Type

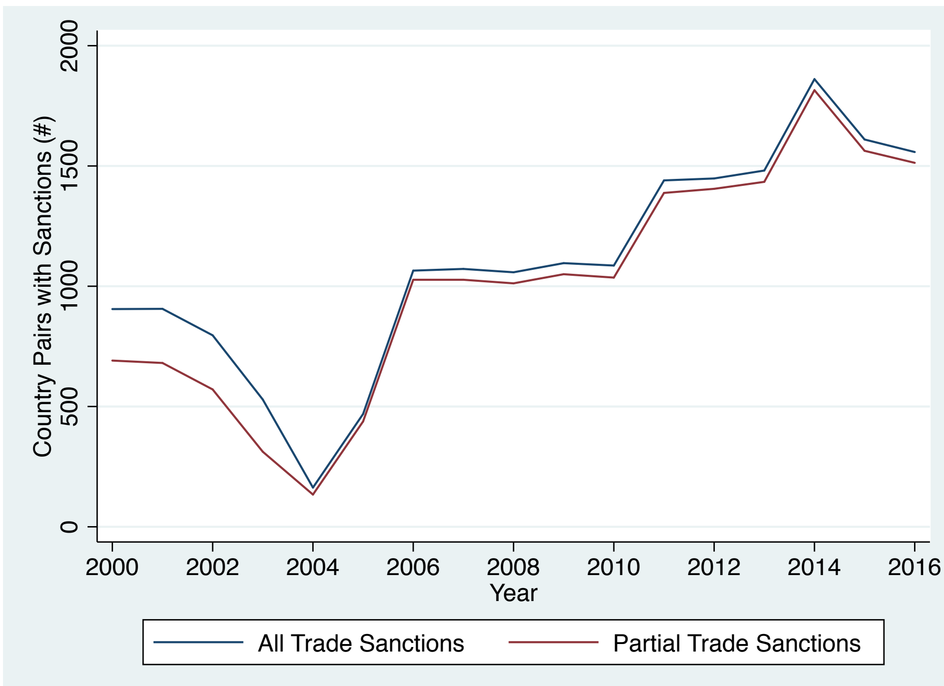
Notes: This table lists the active sanction cases (2000-2016), which are used to obtain our main results. For convenience, the cases are sorted by the name of the sanctioned/target country in column (5). Column (1) includes an ID. Columns (2) and (3) report the start and the end year of the sanction, respectively. Some sanctions do not actually end in 2016, however, this year is listed because it is the last year in the estimating sample. Columns (4) and (5) list the sanctioned/target and sanctioning/sender countries and regions, respectively. Finally, column (6) describes the type of trade sanctions. European Union (+) denotes cases where the EU was joined by other European countries. The total list of countries that joined the EU in at least some of the listed cases includes Cyprus, Malta, Turkey, Croatia, Macedonia, Montenegro, Iceland, Albania, Serbia, Bosnia and Herzegovina, Liechtenstein, Norway, Ukraine, Moldova, Armenia, Georgia, Switzerland. However, not all of these countries join the EU sanctions at all times. In some cases European Union (+) only includes a subset of additional countries. For details, we refer the reader to the description of the original GSDB data at https://www.globalsanctionsdatabase.com.

Table 3: Evolution of Trade Sanctions, 2000-2016

Year	All Sanctions	Complete	Partial
2000	905	214	691
2001	906	225	681
2002	796	225	571
2003	529	217	312
2004	163	29	134
2005	469	31	438
2006	1065	38	1027
2007	1072	45	1027
2008	1058	46	1012
2009	1096	46	1050
2010	1086	50	1036
2011	1440	52	1388
2012	1448	43	1405
2013	1481	47	1434
2014	1861	46	1815
2015	1610	47	1563
2016	1558	45	1513

Notes: This table reports the number of country-pairs that were affected by trade sanctions during the period 2000-2016. Column (1) lists the year. Column (2) lists the total number of country pairs affected by trade sanctions regardless of type. Finally, columns (3) and (4) decompose the numbers from column (3) into complete vs. partial sanctions, respectively. Figure 5 visualizes the data from this table.

Figure 5: Evolution of Trade Sanctions, 2000-2016



Notes: This figure visualizes the data from Table 3. We only report the evolution of partial and total trade sanctions. The evolution of the complete trade sanctions can be traced as the difference between the two curves.

Table 4: On the Impact of Economic Sanctions on Mining Trade

	A. Aggregate Estimates			B. Sectoral Estimates		
	GRAV	FES	TYPE	COAL	OIL	OTHR
	(1)	(2)	(3)	(4)	(5)	(6)
LN_DIST	-1.301					
	(0.090)**					
CNTG	0.380					
	(0.190)*					
LANG	0.151					
	(0.118)					
CLNY	0.638					
	(0.254)*					
WTO	0.978	-0.053	-0.068	0.349	-0.143	-0.060
	(0.155)**	(0.117)	(0.117)	(0.194)+	(0.231)	(0.092)
RTA	0.507	-0.077	-0.077	0.178	-0.177	0.066
	(0.117)**	(0.082)	(0.082)	(0.087)*	(0.117)	(0.057)
TRADE_SANCT	0.170	-0.065				
	(0.203)	(0.147)				
COMPLETE_SANCT			-0.587	-2.377	-0.579	-0.796
			(0.293)*	(0.949)*	(0.295)+	(0.968)
PARTIAL_SANCT			-0.044	-0.052	-0.065	-0.135
			(0.154)	(0.134)	(0.188)	(0.172)
N	538902	538741	538741	75057	92383	307300

Notes: This table reports estimates of the impact of economic sanctions on trade in the Mining sector. The dependent variable in each specification is bilateral trade flows in levels, and the estimator is always PPML. All estimates are obtained with exporter-industry-time fixed effects, importer-industry-time fixed effects, and time-varying industry border fixed effects. In addition, the estimates in columns (2) to (6) also employ directional country-industry-pair fixed effects. The estimates of all fixed effects are omitted for brevity, but are available by request. The results in panel A are obtained by pooling together the data across all five mining industries in our sample. The results in panel B are for the two major mining industries, i.e., 'Mining of hard coal' and 'Extraction crude petroleum and natural gas', together with a combined category for 'Other Mining'. Column (1) reports estimates that are obtained with the set of standard gravity variables. Column (2) introduces directional country-industry-pair fixed effects, which are used in all subsequent specifications. Column (3) allows for differential effects depending on whether the trade sanctions were complete or partial. Finally, columns (4) to (6) of panel B deliver estimates from the same specification as in column (3), however for the individual categories of 'Mining of hard coal', 'Extraction crude petroleum and natural gas', and 'Other Mining', respectively. All standard errors are clustered by product-country-pair. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for further details.

Table 5: Economic Sanctions and the Oil Trade of Russia and Iran

	A. Average	B. Russia			C. Iran		
	Estimates	ALL	EU	ASYMM	ALL	EU	EU2012
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
WTO	-0.143	-0.152	-0.153	-0.153	-0.177	-0.177	-0.175
	(0.231)	(0.228)	(0.229)	(0.229)	(0.230)	(0.230)	(0.230)
RTA	-0.177	-0.176	-0.175	-0.175	-0.173	-0.173	-0.174
	(0.117)	(0.117)	(0.117)	(0.117)	(0.117)	(0.117)	(0.117)
COMPLETE_SANCT	-0.579	-0.583	-0.582	-0.582	-0.599	-0.599	-0.597
	(0.295)$^{+}$	(0.295)*	(0.295)*	(0.295)*	(0.291)*	(0.291)*	(0.292)*
PARTIAL_SANCT	-0.065	0.067	0.071	0.071	0.012	0.012	-0.012
	(0.188)	(0.188)	(0.189)	(0.189)	(0.200)	(0.200)	(0.203)
RUS_ALL		-0.323					
		(0.206)					
RUS_NOEU			0.364	0.364	0.354	0.354	0.349
			(0.316)	(0.316)	(0.319)	(0.319)	(0.323)
RUS_EU			-0.484	-0.484	-0.492	-0.492	-0.551
			(0.170)**	(0.170)**	(0.171)**	(0.171)**	(0.172)**
EU_RUS				-2.477	-2.460	-2.460	-2.459
				(1.153)*	(1.157)*	(1.157)*	(1.159)*
IRN_ALL					0.546	0.548	0.542
					(0.153)**	(0.169)**	(0.169)**
IRN_EU						0.541	0.765
						(0.185)**	(0.188)**
IRN_EU_2012							-1.886
							(0.292)**
N	92383	92383	92383	92383	92383	92383	92383

Notes: This table reports estimates of the impact of economic sanctions on trade of crude petroleum and natural gas. The dependent variable in each specification is bilateral trade flows in levels, and the estimator is always PPML. All estimates are obtained with exporter-time fixed effects, importer-time fixed effects, directional country-pair fixed effects, and time-varying border fixed effects. The estimates of all fixed effects are omitted for brevity, but are available by request. Top ease comparison, column (1)/panel A is a reprint of the main estimates from column (5) of Table 4. The estimates in panel B focus on the sanctions on Russia. Column (2) isolates the sanction on Russia (RUS_ALL). Column (3) allows for differential effects of the sanction on Russia on trade with the European Union (RUS_EU) vs. the rest of the sender countries (RUS_NOEU), including Australia, Canada, Japan, New Zealand, Switzerland and the United States. Column (4) further allows for asymmetric effects of the sanction on Russian exports to the EU (RUS_EU) vs. EU exports to Russia (EU_RUS). Finally, the estimates in panel C focus on the sanctions on Iran. Column (5) isolates the effects sanction on Iran (IRN_ALL). Column (6) allows for differential effects of the sanction on Iran on trade with the European Union (IRN_EU) vs. the rest of the sender countries (IRN_ALL), including many countries as par of the UN sanction on Iran. Finally, column (7) further allows for an additional effect of the complete EU oil embargo on Iran from 2012 ($IRN_EU_$2012). All standard errors are clustered by country pair. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for further details.