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Welfare implications of trade sanctions against Russia

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Welfare implications of trade sanctions against Russia*

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Abstract

Since the beginning of the war between Russia and Ukraine in 2022, Western countries have been discussing and then implementing new trade sanctions against Russian fossil fuels. This paper quantifies such policies' trade and welfare effects using a general equilibrium model with 92 countries and 65 intermediate products and sectoral linkages. The paper breaks down the effects of the bans on gas, crude and refined oil, and coal, and discusses the impact of alternative coalitions of sanctioning countries. In the most stringent case, the model predicts welfare losses of about 16.8% in Russia and 0.42% in the sanctioning countries. These losses are very heterogeneous across sanctioning countries. The OECD countries have an important role as their participation in sanction policies significantly influences expected outcomes in Russia. Meanwhile, should only EU countries implement fossil fuel sanctions, their welfare losses are predicted to be 3.3% on average.

JEL Codes: F13, F14, F17

Keywords: trade shocks, sanctions, welfare outcomes

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1 Introduction

The world economy has faced a series of important trade shocks in the last decades. However, in February 2022, the Russian military invasion of Ukraine initiated an unprecedented series of trade sanctions and led to dramatic economic shocks in the European region. Since Russian fossil products accounted for about half of the Russian trade balance and significantly helped the Russian government's war funding, Western countries seriously considered and began implementing import bans on those goods. While those bans are expected to curb the Russian government's foreign policy, sanctioning countries also have to cope by finding alternative fossil energy sources. As welfare losses are borne by both sanctioned and sanctioning countries, it is important to provide a quantitative assessment of those policies to inform economic and political policymakers on the Russian government's behavior and the support of the populations inside and outside Russia.

As a case in point, crude oil and natural gas are important trade sectors between Russia and the EU. In 2019, crude oil represented 24% and petroleum gases 5.3% of Russian exports. While many sanctioning countries did not want to introduce a total ban against crude oil, some of them declared to stop purchasing crude oil from Russia (e.g. Germany in January 2023).[1] Natural gas is an interesting case because the EU imported 40% of its total consumption from Russia in 2021. Nevertheless, imports of Russian gas fell by 2022, in particular after the breakdown of the Nord-Stream-2 gas pipeline. Starting from February 2023, the EU also banned the import from Russia of refined petroleum products, such as diesel fuel.[2] Imports of coal have been banned with the introduction of the fifth package of sanctions in August 2022.

The objective of this paper is to assess the potential welfare costs of the trade sanctions and bans imposed by Western countries on Russia's fossil exports. We run a series of counterfactual exercises on a 92-country 65-sector model extending Caliendo and Parro (2015). We consider bans on coal, gas, crude oil, and refined products of coal and petroleum and assess the trade and welfare implications of various coalitions of sanctioning countries. We quantify the impact on Russia's welfare and real consumption for four sets of coalition countries (G7, EU, OECD, and all of these) and four banned sectors (coal, natural gas, crude oil, and refined products of coal and oil). As of the current date, the above embargoes have been partially implemented and can be observed

[1] For details, refer to https://www.bloomberg.com/news/articles/2022-12-20/germany-says-it-won-t-be-buying-russian-oil-at-all-in-2023?leadSource=uverify%20wall

[2] See https://time.com/6253071/eu-embargo-russian-diesel/

in the data. Nevertheless, isolating their effects proves challenging due to their intertwining with macroeconomic shocks such as the Brexit adjustment, post-Covid recovery, the USA-China trade war, and OPEC oil restrictions. The present quantification exercise provides a unique opportunity to untangle the impact of each embargo and coalition on trade patterns and the welfare of countries.

In this paper, we first highlight that the ban on refined products of coal and oil has a much stronger welfare impact on Russia than the others. Furthermore, a ban on all fossil sectors by a coalition of the G7, the EU, and the OECD respectively yields a welfare loss of 7.2%, 12.26%, and 16.57% for Russia. As a result, the coalition of the OECD countries has the most effective impact on Russian welfare. The welfare impact on sanctioning countries is highly heterogeneous. In particular, the members of the EU coalition incur an average of 3.25% welfare loss. Fossil fuel producers in the coalition(s) gain. In the case of a full embargo by all countries of G7, the EU, and the OCDE, Norway not only improves its welfare by eleven percent but also, the U.S.A. and the UK improve theirs by about half a percent. The countries staying outside the sanctions may gain or lose. In particular, India and China respectively gain about a half and a third of a percent welfare. The analysis finally allows us to detail the sectors and trade partners that are responsible for the welfare changes in each country. We highlight the case of Germany which had a strong dependency on Russian fuels before the sanctions. The embargoes make it shift its gas supply from Norway and the Netherlands and its oil supply from a very diversified set of oil producers. The embargoes negatively affect its chemical, machinery, and motor vehicle industries. All in all, it loses about three percent of its welfare.

The paper contributes to the economic literature on the costs of trade sanctions, the costs of the breakdown of trade relationships, and the benefits of trade agreements. First, sanctions and embargoes have been discussed for their effects on trade and welfare. For instance, Heilmann (2016) studies the effect of consumer boycotts on trade, Haidar (2017) the sanctions on Iran, Dreger et al. (2016), Crozet and Hinz (2020), and Hinz and Monastyrenko (2022) the sanctions and counter-sanctions after the Russian invasion of Crimea. Our paper furthermore relates to the very recent literature on the general-equilibrium evaluation of the sanctions against the Russian Federation after 2022. Hausmann et al. (2022) study the potential export restrictions on Russian goods and highlight the goods and country coalitions that impact the most the sanctioned country. Imbs and Pauwels (2023) develop an approximation approach of direct and indirect effects of embargoes. They emphasize the strong indirect effects of embargoes and the important impacts on the bordering countries that have kept a strong trade relationship. In an approach similar to ours, Chowdhry et al. (2023) study the coalitions implementing the sanctions against Iran and Russia using Caliendo and Parro (2015)'s model and similar data. By contrast, our paper however concentrates on the embargoes of Russian fossil fuels and explores only a subset of coalitions.[3]

Second, the paper relates to the study of the negative welfare implications of the breakdown of trade relationships and the rise of barriers to the free movement of services and people (Irwin, 2005; O'Rourke, 2007; Feyrer, 2009; Walker, 2017). In particular, Dhingra et al. (2017) calculated that the UK's exit from the EU (Brexit) implied welfare losses of about 1.3% or 2.5% in the UK according to whether it has hard or soft implications on trade relationships (soft and hard Brexit). Bevington et al. (2019) confirm this result and come up with a range between 1.7% and 2.5%.

Third, the paper relates to the literature on the welfare assessment of trade unions. For instance, Berlingieri et al. (2018) estimate that trade agreements concluded by the European Union between 1993 and 2013 increased quality by 7% and decreased consumer price indices by 0.24%. Felbermayr et al. (2022a) argue that a complete breakdown of EU integration reduces intra-Europe trade by 25% and implies welfare losses of 23%. Felbermayr et al. (2022b) moreover find important heterogeneity between pairs of trading countries as, in particular, the UK would have lost between 0.93% and 2.76% of its real consumption.

Finally, the paper relates to the economic literature on the recent trade policy changes imposed by the U.S. administration through its withdrawal from the Trans-Pacific Partnership and the introduction of protectionist tariffs on steel and aluminum. Fajgelbaum et al. (2020) show that this entire episode implied losses for U.S. consumers and firms reflected in a loss in aggregate real income of 0.04% of the U.S. GDP. As in this literature, this paper uses a model with many countries and sectors to assess the welfare implication of sanctions against Russia since 2022. The paper contributes to the literature on the quantitative analysis of major trade shocks.

The remainder of this paper is organized as follows. Section 2 introduces the baseline model while Section 3 presents our data and variable construction. Section 4 discusses the counterfactual analyses of the sanctions on Russian fossil exports. Section 5 concludes.

[3] Unlike this paper, Chowdhry et al. (2023) do not study embargoes (100% fall in import). They rather study the trade cost associated with the short-run partial-equilibrium fall in trade flows and apply those trade costs to the Caliendo and Parro (2015)'s general equilibrium model.

2 Model

The economy includes a set of countries $n, i \in \{1, ..., N\}$ and sectors $j, k \in \{1, ..., J\}$. Each country n hosts a fixed number of workers L_n and land surface M_n. The production uses labor and natural resource factors that are mobile across sectors but not countries. Markets are perfectly competitive. Each sector j produces a final good and a set of intermediate goods ω^j. Households consume the final goods while firms use both final and intermediate goods for production. Final goods are consumed locally whereas intermediate goods are traded and intermediate services are non-tradeable. For the sake of conciseness, all sum and product operators, $\sum_i$, $\sum_j$, $\sum_k$ and $\prod_j$ are applied on all country indices and all sector indices.[4]

2.1 Consumers

In country n, a representative consumer chooses her consumption C_n^j of final goods that maximize her utility

$$U_n = \prod_j \left(C_n^j\right)^{\alpha_n^j} \tag{1}$$

subject to her budget constraint $\sum_j P_n^j C_n^j = I_n / L_n$ where P_n^j is the price of the final good j and I_n is the country income. The parameters α_n^j, measure the intensity of their preferences for goods j in country n, with $\sum_j \alpha_n^j = 1$.

2.2 Producers

Intermediate goods In country n and sector j, competitive firms produce the intermediate good ω^j using local labor and a set of final goods. Their production function is given by

$$q_n^j(\omega^j) = z_n^j\left(\omega^j\right)\left[l_n^j\left(\omega^j\right)\right]^{\gamma_n^{lj}}\left[m_n^j\left(\omega^j\right)\right]^{\gamma_n^{mj}}\prod_k\left[B_n^{kj}\left(\omega^j\right)\right]^{\gamma_n^{kj}}, \tag{2}$$

where $z_n^j\left(\omega^j\right)$ is the firm idiosyncratic productivity, $l_n^j\left(\omega^j\right)$ the local labor input, $m_n^j\left(\omega^j\right)$ the natural resource input, and $B_n^{kj}\left(\omega^j\right)$ the input of final goods (materials) from sector k into sector j. In this Cobb-Douglas specification, the parameters γ_n^{lj} and γ_n^{mj} specify the use of labor and natural resources in production and yield the share of labor input in the total cost of intermediate goods ω^j in sector j. The parameters γ_n^{kj} specify the use of goods from sector k in sector j and yield the

[4]That is $\sum_i$, $\sum_j$, $\sum_k$ and Π_j stand for $\sum_{i=1}^N$, $\sum_{j=1}^J$, $\sum_{k=1}^N$, $\prod_{j=1}^N$.

shares of the final good k used for this production in sector j and country n. Under constant returns to scale, we have $\gamma_n^{lj} + \gamma_n^{mj} + \sum_{k=1}^{J} \gamma_n^{kj} = 1$. The firm idiosyncratic productivity is drawn from a Frèchet distribution $F_n^j(z) = \exp\left(-\lambda_n^j z^{-\theta^j}\right)$ where λ_n^j is a country-sector productivity shifter and θ^j is a sector-specific dispersion parameter.

Production cost is given by $w_n l_n^j\left(\omega^j\right) + v_n m_n^j\left(\omega^j\right) + \sum_k P_n^k B_n^{kj}\left(\omega^j\right)$ where w_n is the local wage, v_n is the natural resource price and P_n^k are the prices of final goods. The firm chooses the input mix that minimizes its cost per unit of intermediate goods. It can be shown that the unit cost is given by $c_n^j / z_n^j\left(\omega^j\right)$ where c_n^j is the cost of an input bundle given by

$$c_n^j = \Gamma_n^j \left(w_n\right)^{\gamma_n^{lj}} \left(v_n\right)^{\gamma_n^{mj}} \prod_k \left(P_n^k\right)^{\gamma_n^{kj}}, \tag{3}$$

where Γ_n^j is a the bundle of parameters γ_n^{lj} and γ_n^{mj} and γ_n^{kj}. Factor costs have constant proportionality so that

$$\frac{v_n m_n^j\left(\omega^j\right)}{\gamma_n^{mj}} = \frac{w_n l_n^j\left(\omega^j\right)}{\gamma_n^{lj}}. \tag{4}$$

Equating the factor supplies L_n and M_n to the aggregate demands by firms in all sectors in country n, $\sum_j \int \frac{w_n l_n^j(\omega^j)}{\gamma_n^{lj}} \mathrm{d}\omega^j$ and $\sum_j \int m_n^j\left(\omega^j\right) \mathrm{d}\omega^j$ yields the following relationship between local factor prices:

$$\frac{v_n}{w_n} = \frac{\gamma_n^{mj}}{\gamma_n^{lj}} \frac{L_n}{M_n}. \tag{5}$$

At given labor forces and natural resources, factor prices move one to one.

Final goods Final goods are produced with the intermediate goods sourced from all countries. In country n and sector j, final-good producers are endowed with the production function

$$Q_n^j = \left[\int \sum_i \left(r_{in}^j\left(\omega^j\right)\right)^{1-1/\sigma^j} \mathrm{d}\omega^j\right]^{\frac{\sigma^j}{\sigma^j-1}}, \tag{6}$$

where $r_i^j\left(\omega^j\right)$ is the quantity of intermediate input sourced from country i and σ^j is the elasticity of substitution between intermediate goods. Final-good producers import intermediate goods and pay an iceberg cost κ_{in}^j from country i to country n where $\kappa_{in}^j \geq 1$ and $\kappa_{ii}^j = 1, \forall n \neq i$. The price of an intermediate good in the destination country n is given by $p_{in}^{j}\left(\omega^{j}\right)=\kappa_{in}^{j} c_{i}^{j}/z_{i}^{j}\left(\omega^{j}\right)$. Non-tradeable goods cannot be moved across borders because their trade costs are infinite, i.e. $\kappa_{in}^{j}=\infty$ and $\kappa_{nn}^{j}=1$, $\forall n \neq i$.

Under perfect competition, final good producers minimize their cost $\int \sum_{i}\left(p_{in}^{j}\left(\omega^{j}\right) r_{in}^{j}\left(\omega^{j}\right)\right) \mathrm{d}\omega^{j}$ where $p_{in}^{j}\left(\omega^{j}\right)=\kappa_{in}^{j} c_{i}^{j}/z_{i}^{j}\left(\omega^{j}\right)$ is the import price of the intermediate good. They source each intermediate input ω^{j} from the country with the lowest import price $p_{in}^{j}\left(\omega^{j}\right)=\arg\min_{i} p_{in}^{j}\left(\omega^{j}\right)=\arg\min_{i} \kappa_{in}^{j} c_{i}^{j}/z_{i}^{j}\left(\omega^{j}\right)$. Given the properties of Frèchet distribution, the unit cost of a final good is given by $A^{j}\left(\Phi_{n}^{j}\right)^{-1/\theta^{j}}$ where

$$\Phi_{n}^{j}=\sum_{i=1}^{N} T_{in}^{j} \quad \text{and} \quad T_{in}^{j}=\lambda_{n}^{j}\left(c_{n}^{j} \kappa_{in}^{j}\right)^{-\theta^{j}}. \tag{7}$$

and $A^{j} \equiv\left[\Gamma(1+(1-\sigma^{j})/\theta^{j})\right]^{1/(1-\sigma^{j})}$ is a sector-specific constant where Γ is the Gamma function. The variable Φ_{n}^{j} represents a sufficient statistic of the states of technology across countries, input costs, geographic barriers, and tariff policies. It is correlated across sectors due to input-output linkages.

Under perfect competition, the prices of final goods are equal to their costs, $P_{n}^{j}=A^{j}\left(\Phi_{n}^{j}\right)^{-1/\theta^{j}}$, and product markets clear as

$$Q_{n}^{j}=C_{n}^{j}+\sum_{k=1}^{j} \int B_{n}^{kj}(\omega^{k}) \mathrm{d}\omega^{k}. \tag{8}$$

This condition equates the supply of each final good with its demands by local consumers and world producers of intermediate goods.

2.3 Expenditures

The expenditure on a final good j in country n is given by $X_{n}^{j}=P_{n}^{j} Q_{n}^{j}$. The share of country n's expenditure on intermediate good j from i is given by the probability:

$$\pi_{ni}^{j}=\frac{X_{ni}^{j}}{X_{n}^{j}}=\Pr\left[\frac{c_{i}^{j} \kappa_{ni}^{j}}{z_{i}^{j}\left(\omega^{j}\right)} \leq \min_{h \neq j}\left\{\frac{c_{h}^{j} \kappa_{nh}^{j}}{z_{h}^{j}\left(\omega^{j}\right)}\right\}\right]. \tag{9}$$

Using again the properties of Frèchet distributions, this gives

$$\pi_{ni}^{j} = \frac{\lambda_i^j \left(c_i^j \kappa_{ni}^j\right)^{-\theta^j}}{\sum_{i=1}^{N} \lambda_i^j \left(c_i^j \kappa_{ni}^j\right)^{-\theta^j}}. \tag{10}$$

The unit price of the composite intermediate good j is then equal to, $P_n^j = \left[\int \left(p_n^j\left(\omega^j\right)\right)^{1-\sigma^j} \mathrm{d}\omega^j\right]^{\frac{1}{(1-\sigma^j)}}$. With Cobb-Douglas preferences, the consumption price index in country n becomes $P_n = \prod_j \left(P_n^j/\alpha_n^j\right)^{\alpha_n^j}$ so that the equilibrium utility simplifies to $U_n = (I_n/L_n)/P_n$.

2.4 Trade balance and welfare measures

Total expenditure on goods j in country n is defined as

$$X_n^j = \alpha_n^j I_n + \sum_k \gamma_n^{jk} \sum_i \frac{\pi_{in}^k}{1+\tau_{in}^k} X_i^k, \tag{11}$$

where $I_n = w_n L_n + v_n M_n + R_n + D_n$ is the final absorption that equals the sum of the GDP ($w_n L_n + v_n M_n$), tariff revenue (R_n) and trade deficit (D_n). The deficit in country n is equal to the sum of sectoral deficits: $D_n = \sum_k D_n^k$. The tariff revenue includes all tariff incomes within the country's imports: that is, $R_n = \sum_j \sum_i \tau_{ni}^j IM_{ni}^j$ where τ_{ni}^j is the tariff on import values IM_{ni}^j from country i to n in sector j. The full trade cost is equal to $\kappa_{ni}^j = t_{ni}^j(1+\tau_{ni}^j)$ where t_{ni}^j is a non-tariff iceberg trade cost.

Import values IM_{ni}^j and export values EX_{ni}^j are defined through expenditure values and shares, X_n^j and π_{ni}^j , as

$$IM_{ni}^j = X_n^j \frac{\pi_{ni}^j}{1+\tau_{ni}^j} \quad \text{and} \quad EX_{ni}^j = X_i^j \frac{\pi_{in}^j}{1+\tau_{in}^j}. \tag{12}$$

Therefore, the trade balance

$$\sum_j \sum_i X_n^j \frac{\pi_{ni}^j}{1+\tau_{ni}^j} = D_n + \sum_j \sum_i X_i^j \frac{\pi_{in}^j}{1+\tau_{in}^j} \tag{13}$$

Finally, we define two measures of welfare and economic activity. On the one hand, following Caliendo and Parro (2015), we measure the utilitarian welfare as the sum of individuals' utilities in the country as

$$W_n = L_n U_n = \frac{I_n}{P_n}. \tag{14}$$

On the other hand, in the spirit of Felbermayr et al. (2022b), we also measure the economic activity as the real consumption by all local workers and firms given by

$$X_n^c = \frac{1}{P_n} \sum_j X_n^j. \tag{15}$$

Although this measure is taken as an indicator of welfare by Felbermayr et al. (2022b), it reports a higher value than the welfare accrued on the income of the local consumers-workers who own local factors. By (11), this can indeed be broken down as the workers' and firms' real consumption of input as $X_n^c = I_n/P_n + (1/P_n) \sum_i \sum_j \sum_k \gamma_i^{jk} \frac{\pi_{in}^k}{1+\tau_{in}^k} X_i^k$, which is larger than I_n/P_n. Finally, for the sake of clarity, we will also present many results for sets $\mathcal{N}$ of countries. In this case, we aggregate the measures of welfare and economic activity as $\sum_{n \in \mathcal{N}} W_n$ and $\sum_{n \in \mathcal{N}} X_n^c$.

In this paper, we study the implementation of trade embargoes as shocks in bilateral trade costs. As in Caliendo and Parro (2014), we use the exact hat algebra proposed by Dekle et al. (2008) and define the general equilibrium in terms of variable changes. This approach allows us to formulate and solve the equilibrium outcome without reference to country productivities and non-tariff trade costs (see Appendix A). In particular, trade costs are assumed to be consistent with observed trade flows. As a point in case, the trade flows of natural gas reflect the operating transport networks of gas (e.g. Yamal-Europe and Nord Stream 1 pipelines respectively flowing to Poland and Germany).

3 Data

This section describes the data sources used for model calibration. The virtue of Caliendo and Parro (2015)'s framework lies in its sparsity of parameters and variables compared to traditional computable general equilibrium models. The associated 'exact hat algebra' approach allows for solving changes in equilibrium variables and advantageously reduces the number of variables in the computation process. Here, we discuss the construction and use of input-output matrices.

3.1 Trade flows and elasticities

We calibrate the model using the GTAP11-a production and trade data for the year 2017. The value of imports of tradeable commodities at CIF prices denoted as VCIF, is used to calibrate the trade flows. Consistent data are obtained for 119 countries. Trade elasticities θ^j for the tradeable sectors are sourced from the study by Fontagné et al. (2022). These elasticities indicate the degree to which trade flows adjust in response to changes in trade costs. For the 20 non-tradeable sectors, we assign values equal to the mean elasticity of the tradeable sectors, which is 5.4. This figure is close to the industry-specific mean trade elasticity of 5, as reported in Costinot and Rodriguez-Clare (2014).

3.2 Tariffs

The data on bilateral tariffs are sourced from the most recent available year, 2014, as provided in the Market Access Map (MacMap) issued by The International Trade Centre (Bouet et al., 2004)). We have consistent tariff values for 138 countries. Tariffs recorded by HS6 products are unambiguously matched with a corresponding GTAP11-a sector. Tariffs are aggregated to the GTAP11-a level by taking a simple average. The diagonal elements of the tariff matrix, representing the same destination and origin, are set to zero. Note that the sectors 'raw milk' (rmk) and 'other mining extraction' (oxt) have no reported tariffs. For these sectors, we apply the tariffs of 'Milk: dairy products' (mil) and 'Coal' (coa), respectively. Additionally, we treat the sector 'Recreation & Other Services' (ros) as non-tradeable, although MacMap reports a few tariff values for it.

3.3 Rest of the World

Due to differences in the sets of countries included in the tariff and input-output datasets, we obtain complete information only for 92 countries. To account for the rest of the world (ROW), we aggregate the data from the 27 GTAP11-a countries for which tariff data are not available. For each sector, the import and export values of the ROW are calculated as the sum of the import and export values of these 27 countries. The input-output coefficients for the ROW are computed as the average values from these countries. The bilateral tariffs applied to the ROW are determined by taking the average tariffs across all MacMap countries that are not included in the GTAP11-a database.

3.4 Input-output

The significant advantage of this study lies in its coverage of a large portion of the global economy, enabling a comprehensive representation of oil-producing countries. This aspect is particularly relevant for examining the impact of sanctions on Russia. The GTAP11-a database includes detailed input-output tables for 121 countries, accounting for 98% and 92% of the world's GDP and population, respectively. It also encompasses 20 of the top 25 oil-producing countries.[5] The GTAP11-a database includes 65 sectors, distinguishing between services, manufacturing, and agriculture.

To construct input-output matrices, we use the domestic purchases at basic prices $VDFB_n^{jk}$ by firms in sector j from sector k (Value of Domestic purchases by Firms at Basic prices), the imported purchases at basic prices by firms in sector j from sector k, $VMFB_n^{jk}$ (Value of Imports by Firms at Basic prices) and, finally, the primary factor purchases (labor and natural resources) at basic prices by firms in sector j, $EVFB_n^{lj}$ and $EVFB_n^{mj}$ (Factor Value by Firms at Basic prices). In this model, $EVFB_n^{lj}$ aggregates all primary-factor values of labor (agriculture/unskilled, service, clerk, technician/associate professional and officials/managers). We exclude capital and land factors.

The matrix of input-output coefficients is then determined as

$$\gamma_n^{ij} = \frac{VDFB_n^{ij} + VMFB_n^{ij}}{GO^j}, \quad \gamma_n^{lj} = \frac{EVFB_n^{lj}}{GO_n^j} \text{ and } \gamma_n^{mj} = \frac{EVFB_n^{mj}}{GO_n^j}, \tag{16}$$

where GO_n^j is the gross output in final sector j given by the sum of all inputs employed in production:

$$GO_n^j = EVFB_n^{lj} + EVFB_n^{mj} + \sum_k (VDFB_n^{jk} + VMFB_n^{jk}). \tag{17}$$

This readily yields $\gamma_n^{lj} + \gamma_n^{mj} + \sum_k \gamma_n^{ik} = 1$. Note that the gross output is proxied by the sum of all inputs employed in the production. We make sure that the GO_n^j matrix doesn't contain any zeros.

3.5 Validation

To validate the model quantification, we replicate the predictions of well-known studies on the impact of trade shocks. First, we study the outcomes of Brexit by relying on the papers of Dhingra et al. (2017) and Felbermayr et al. (2022b). We replicate soft and hard Brexit scenarios as closely as

[5]The following oil producers are excluded from our study due to unavailable input-output or trade data: Iraq, Kuwait, Venezuela, Angola, and Algeria.

Table 1: Model validation.

Panel A: Brexit			
Brexit	UK change, %	Total utility	Real firms consumption
Soft: NTBs 2.77%	This model	– 1.37	– 0.65
	Dhingra et al. (2017)	– 1.3	—
Soft: NTBs 1.5%	This model	– 0.8	– 0.39
	Felbermayr et al. (2022b)	—	– 0.93
Hard: NTBs 8.31%	This model	– 3.4	– 1.52
	Dhingra et al. (2017)	– 2.7	—
Hard: NTBs South Korea	This model	0.28	– 0.18
	Felbermayr et al. (2022b)	—	– 2.76
Panel B: U.S. - China trade war			
US-China trade war	US change, %	Total utility	Real firms consumption
No retaliation	This model	-2.42	-2.59
	Fajgelbaum et al. (2020)	0.00	0.00
Retaliation	This model	-4.83	-3.12
	Fajgelbaum et al. (2020)	—	– 0.93

Note: This table presents the percentage changes in country utility and real consumption for the counterfactual simulations of Brexit (Panel A) and the U.S.-China trade war (Panel B), comparing these with findings from related literature. For Soft Brexit, we consider tariff equivalents of small non-tariff barriers (NTBs), while Hard Brexit involves larger equivalents. In line with Felbermayr et al. (2022b), we set the bilateral tariffs between the UK and EU to mirror those between South Korea and the EU. The US-China trade patterns are based on tariffs imposed by the US in scenarios without retaliation, and by China, Canada, Mexico, Russia, Turkey, and the EU in scenarios with retaliation, as detailed in Fajgelbaum et al. (2020). The simulations are based in GTAP data for the year 2017.

possible to the definitions provided in these papers. Then, we closely follow the study of Fajgelbaum et al. (2020) to replicate the U.S.-China trade war. Our findings are summarized and compared with the results of these reference studies in Table 1. Panel A contains simulations of Brexit, whereas Panel B reports results for the U.S.-China trade dispute.

In the soft scenario presented by Dhingra et al. (2017), Brexit is modeled as an increase in tariffs by 2.77%. According to their findings, this leads to a reduction in total utility in the UK by 1.3%. Our simulation predicts a very similar result, with a decrease of -1.37%. In the soft scenario discussed by Felbermayr et al. (2022b), the rise in bilateral EU-UK tariffs is estimated at 1.5%. Those authors predict a 0.39% decline in the UK's real consumption whereas our quantified model predicts a more pronounced reduction of 0.93%.

The hard Brexit scenario is typically modeled as the tariff equivalent of large non-tariff barriers (NTBs). Dhingra et al. (2017) quantify it to 8.31%. Their model predicts a 2.7% UK utility loss while our model returns a slightly higher loss of -3.4%. Felbermayr et al. (2022b) match the bilateral tariffs between the UK and EU to those between South Korea and the EU. Those authors predict a 2.76% welfare loss, which contrasts with our milder welfare reduction of 0.18%.

Our final model-validation exercise replicates the U.S.-China trade war. We apply the protectionist tariffs implemented by the U.S. administration in January 2021, as computed by Fajgelbaum et al. (2020). We first test the scenario without retaliation from U.S. trade partners, followed by a scenario with retaliation from China, Canada, Mexico, Russia, Turkey, and the EU. Our findings are shown in Panel B of Table 1. These authors indicate mild welfare effects, partly because tariff revenues broadly compensate for import loss. Our nevertheless model predicts significantly larger negative impacts than Fajgelbaum et al. (2020), both in terms of total utility and real firms' consumption. This is partly explained by strong discrepancies between the two types of trade models and the data used for calibrations.

To sum up, this model compares relatively well to the other models' predictions of the Brexit economic outcome. Comparisons for the trade war between the USA and China are less obvious because of the discrepancies between this trade model and the present one.

4 Trade sanctions on Russia

In this section, we quantify the impact of embargoes on sanctioned and sanctioning countries. We first present the changes in trade flows for each type of trade sanction that involves a ban on coal, gas, crude oil, and refined products of coal and oil. We then discuss the changes in welfare and real consumption for combinations of those sanctions. Bans are implemented by imposing prohibitively high trade costs on restricted goods. For the sake of realism, we assume that trade has already been disrupted between the two belligerents, Russia and Ukraine.[6] We then compare welfare and real consumption differences with and without sanctions.

[6] Appendix B shows the welfare effects of the trade disruption between Ukraine and Russia.

4.1 Trade flows

We first discuss the impact of embargoes on trade flows when the set of sanctioning countries encompasses the large coalition of G7, EU, and OECD countries. Table 2 to Table 5 separately report this information for each ban on Russian coal, natural gas, crude and refined products of coal and oil, by aggregates of large population or production entities like Russia, OPEC, the US, the EU (including the UK), China, India, and the rest of the countries grouped as Rest of the World (ROW). Rows and columns designate importing and exporting entities.

The changes in trade flows resulting from a Russian coal embargo are presented in Table 2. Russian coal production decreases by USD $20,498$ million, approximately 1.3% of the Russian GDP. These changes are primarily attributed to the supply interruption to the sanctioning countries in the EU and the rest of the world. The EU substitutes about two-thirds of its coal supply loss from its territories, the USA, and the rest of the world. The USA, China, and India are only marginally affected by the embargo. World coal consumption drops by USD 2483 million (the sum of the elements in the last column), which represents about a tenth of the decrease in Russian coal consumption and promotes carbon emission reductions.

Table 2: Changes in trade values of coal.

	Russia	OPEC	U.S.	EU	China	India	ROW	Total
Russia	-1,230	0	0	0	0	0	-314	-1,544
OPEC	1	2	1	0	0	0	3	7
U.S.	-6	0	538	0	0	0	5	537
EU	-9,200	0	1,442	1,681	2	0	2,841	-3,234
China	298	0	4	0	1,565	0	145	2,012
India	47	0	9	0	0	286	123	465
ROW	-10,408	2	950	9	115	3	8,603	-726
Total	-20,498	4	2,944	1,690	1,682	289	11,406	

Note: This table provides information on the post-embargo adjustment of trade values in the sector of coal. The origins of trade flows are in columns and the destinations in rows. ”Rest of the World” (ROW) refers to a group of countries that, within the context of our analysis, falls outside the categories of member nations of the European Union, OPEC countries, the United States, Russia, China, and India. The simulations are based on GTAP data for 2017. All values are in millions of U.S. dollars.

The embargo on Russian natural gas holds particular significance due to recent investments in gas transport infrastructures between the EU and Russia. This is evident in Table 3, where the EU countries imposing sanctions contribute USD $42,769$ million (82%) out of the total USD $51,010$ million decline in Russian gas consumption (about 3% of Russian GDP). The EU, in turn, substitutes approximately 58% of this amount from gas producers in the rest of the world. Only a small percentage results from the increased exports from OPEC and the USA.[7]. Notably, in this quantification exercise, Russia does not substantially redirect its natural gas exports to China and India. The impact on Russia is approximately five times greater than that on the EU (USD $51,010$ million $>$ USD $9,859$ million). The world's gas consumption drops by about a fifth of the Russian loss.

Table 3: Changes in trade values of gas.

	Russia	OPEC	U.S.	EU	China	India	ROW	Total
Russia	-1,044	0	0	0	0	0	-77	-1,121
OPEC	0	1,162	4	0	0	0	64	1,230
U.S.	-83	2	998	0	0	0	516	1,433
EU	-42,769	739	662	6,454	0	0	25,055	-9,859
China	311	-1	-6	0	-1	0	-128	175
India	0	31	13	0	0	123	86	253
ROW	-7,425	2,518	473	12	0	0	5,821	1,399
Total	-51,010	4,451	2,144	6,466	-1	123	31,337	

Note: This table provides information on the post-embargo adjustment of trade values in the sector of gas. The origins of trade flows are in columns and the destinations in rows. ”Rest of the World” (ROW) refers to a group of countries that, within the context of our analysis, falls outside the categories of member nations of the European Union, OPEC countries, the United States, Russia, China, and India. The simulations are based on GTAP data for 2017. All values are in millions U.S. dollars.

Similarly, Table 4 reports the changes in trade flows after the ban on crude oil. Exports from Russia to EU countries fall by USD $61,852$ million, which accounts for the main part of the Russian loss (USD $76,077$ million, or equivalently, 4.8% of GDP). The EU substitutes about a third and a half of this fall from oil producers in OPEC countries and the rest of the world. The contribution of the USA to the EU's oil supply remains small. Russia diverts about a quarter of its trade loss with the EU to China, and a few percent to India. Although Russia incurs a big fall in its exports, world consumption falls by a much smaller amount (sum of elements in the last column).

Finally, Table 5 shows that the embargo on refined products of coal and oil negatively not only impacts the EU but also the USA and the rest of the countries that impose sanctions. The refined product supplies by OPEC and the USA to the EU are far from compensating for the negative supply shock in the EU countries. Again, Russia is not very effective in diverting its exports to China and India.

[7]This is to be compared to the promise of supply of 15 billion cubic tons of liquid natural gas to Europe announced by the USA's president on the 27th of March 2022.

Table 4: Changes in trade values of crude oil.

	Russia	OPEC	U.S.	EU	China	India	ROW	Total
Russia	-24,011	0	0	0	0	0	-1	-24,012
OPEC	0	2,565	0	0	0	0	0	2,565
U.S.	-588	289	9,280	3	2	0	3,601	12,587
EU	-61,852	18,152	2,881	7,695	0	0	28,787	-4,337
China	16,276	-3,282	-528	0	-4,953	0	-4,723	2,790
India	950	126	14	0	0	542	241	1,873
ROW	-6,852	5,314	876	55	57	0	7,756	7,206
Total	-76,077	23,164	12,523	7,753	-4,894	542	35,661	

Note: This table provides information on the post-embargo adjustment of trade values in the sector of crude oil. The origins of trade flows are in columns and the destinations in rows. ”Rest of the World” (ROW) refers to a group of countries that, within the context of our analysis, falls outside the categories of member nations of the European Union, OPEC countries, the United States, Russia, China, and India. The simulations are based on GTAP data for 2017. All values are in millions U.S. dollars.

Overall, each embargo results in Russia experiencing a trade export loss equivalent to a few percent of its GDP. The cumulative export loss amounts to approximately 10% of its GDP (actually, USD $48,815$ million). Various geographical and production entities encounter losses in trade flows, while others see gains. Notably, the EU faces significant import losses across all fossil fuel sectors and struggles to fully offset these losses from alternative suppliers. Russia, in response, partially redirects only its crude oil exports to China, and India increases its imports of Russian fuels to a limited extent. There are no highly noticeable changes in other fossil fuels. By contrast, OPEC countries notably witness a substantial increase in both exports of crude oil and refined products of coal and oil. They only have a marginal rise in natural gas exports. Finally, the USA experiences significant export growth in crude oil and refined products of coal and oil. Although its contribution to the global supply of coal and natural gas is positive, the overall impact of the latter is relatively modest.

4.2 Welfare and economic activity

We now concentrate on welfare effects and study four coalitions which respectively include the G7 countries, the EU countries, the OECD countries, and the union of three coalitions. Results are reported in Tables 6 to 9. We readily observe that larger coalitions imply more substantial welfare losses for the sanctioned country. However, the nature of the coalition has a quantitatively important effect on sanctioned and sanctioning countries. We also explore the implications of sanctions on specific countries

Table 5: Changes in trade values of refined products of coal and oil.

	Russia	OPEC	U.S.	EU	China	India	ROW	Total
Russia	2,223	-10	-17	-645	-173	-7	-188	1,183
OPEC	303	2,143	157	-841	34	80	136	2,012
U.S.	-7,499	17	11,101	-972	149	184	445	3,425
EU	-21,002	1,065	2,154	-2,582	246	401	3,826	-15,892
China	354	-156	-81	-136	5,103	-7	-818	4,259
India	96	-20	10	-94	38	1,954	-66	1,918
ROW	-8,282	628	2,104	-2,755	1,035	1,136	7,809	1,675
Total	-33,807	3,667	15,428	-8,025	6,432	3,741	11,144	

Note: This table provides information on the post-embargo adjustment of trade values in the sector of refined products of coal and oil. The origins of trade flows are in columns and the destinations in rows. "Rest of the World" (ROW) refers to a group of countries that, within the context of our analysis, falls outside the categories of member nations of the European Union, OPEC countries, the United States, Russia, China, and India. The simulations are based on GTAP data for 2017. All values are in millions U.S. dollars.

4.2.1 The G7 countries coalition

Table 6 presents the welfare results for the embargo imposed by the G7 countries[8] and seven combinations of bans on fossil sectors. Among the four fossil fuels (lines 1 to 4), the embargo on natural gas has the most pronounced negative impact on Russian welfare (2.64%), while the ban on coal has the smallest effect. As expected, the most significant reduction in Russian welfare (7.2%) occurs when the embargo encompasses all fossil sectors (line 7). The embargoes exhibit a slightly decreasing return to scope, as the combination of multiple bans results in a smaller impact on Russian welfare loss than each separate ban. For instance, the joint embargo on gas and crude oil decreases welfare by 4.88% compared to 2.64% and 2.38% for each separate ban. The effect of embargoes on real consumption follows similar patterns, being more pronounced for broader embargoes and weaker for natural gas. Real consumption generally decreases, except for the combination of natural gas and crude oil.

According to modern trade theory, the implementation of restrictive protectionist measures inflicts collateral damage on the countries imposing such measures. Our results substantiate this hypothesis in the present case. The embargoes have an overall negative impact on the welfare of the sanctioning countries. Specifically, the ban on Russian natural gas creates the most significant loss (0.34%), mainly because it is highly demanded by the UK, France, Germany, and Italy. However, the welfare consequences of embargoes vary among sanctioning countries, creating both gainers and

[8]The G7 countries are Canada, France, Germany, Italy, Japan, United Kingdom, United States.

Table 6: Welfare outcomes of the embargo imposed by G7 countries, alternative scenarios.

	Δ Total Utility, %			Δ real consumption, %		
Embargo	Russia	sanc. countries	other countries	Russia	sanc. countries	other countries
Coal	-0.78	-0.06	0.05	-0.29	-0.05	0
Natural gas	-2.64	-0.34	0.23	-0.06	-0.28	0
Crude oil	-2.38	0	0.09	-0.17	-0.01	0
Refined products	-1.72	-0.01	0.06	-0.94	0.01	0
Natural gas and crude oil	-4.86	-0.34	0.32	0.15	-0.31	0
Natural gas, crude oil and refined products	-6.66	-0.34	0.37	-0.44	-0.32	0.01
Natural gas, crude oil, refined products and coal	-7.2	-0.4	0.41	-0.47	-0.39	0.02

Note: This table reports results for the counterfactual simulations of the embargo on exports of fossil fuels from Russia to G7 countries. The reported values are in percentage points of the changes. The simulations are based on GTAP data for 2017.

Table 7: Welfare outcomes of embargo imposed by EU countries, alternative scenarios.

	Δ Total Utility, %			Δ real consumption, %		
Embargo	Russia	sanc. countries	other countries	Russia	sanc. countries	other countries
Coal	-0.97	-0.34	0.05	-0.29	-0.22	0
Natural gas	-4.23	-2.49	0.33	0.14	-1.7	0.03
Crude oil	-6.05	-0.18	0.18	0.28	-0.24	0
Refined products	-1.54	-0.17	0.06	-0.94	-0.04	0.01
Natural gas and crude oil	-9.62	-2.7	0.5	0.95	-1.97	0.03
Natural gas, crude oil and refined products	-11.67	-2.92	0.58	0.38	-2.06	0.04
Natural gas, crude oil, refined products and coal	-12.26	-3.25	0.62	0.4	-2.29	0.04

Note: This table reports results for the counterfactual simulations of the embargo on exports of fossil fuels from Russia to EU countries. The reported values are in percentage points of the changes. The simulations are based on GTAP data for 2017.

Table 8: Welfare outcomes of the embargo imposed by OECD countries, alternative scenarios.

	Δ Total Utility, %			Δ real consumption, %		
Embargo	Russia	sanc. countries	other countries	Russia	sanc. countries	other countries
Coal	-1.89	-0.07	0.08	-0.36	-0.12	-0.01
Natural gas	-4.81	-0.36	0.37	0.2	-0.52	0.02
Crude oil	-7.24	0.06	0.29	0.43	-0.08	-0.01
Refined products	-3.14	0	0.11	-1.53	0	-0.01
Natural gas and crude oil	-11.47	-0.31	0.67	1.3	-0.62	0.03
Natural gas, crude oil and refined products	-15.18	-0.32	0.82	0.39	-0.66	0.05
Natural gas, crude oil, refined products and coal	-16.57	-0.4	0.88	0.51	-0.81	0.05

Note: This table reports results for the counterfactual simulations of the embargo on exports of fossil fuels from Russia to OECD countries. The reported values are in percentage points of the changes. The simulations are based on GTAP data for 2017.

losers. Those with a net supply or demand for these fuels experience different effects (refer to the appendix for details on Germany and the USA).

Finally, countries not imposing sanctions have, on average, a slight benefit. They indeed can either sell fuels to the sanctioning countries at higher prices or purchase them from Russia at lower prices.

4.2.2 Larger coalitions

The width of the coalition of sanctioning countries plays a crucial role in shaping welfare outcomes. To quantify this aspect, we present the welfare effects of coalitions comprising EU member countries,

Table 9: Welfare outcomes of embargo imposed by 44 countries, alternative scenarios.

Embargo	Russia	Δ Total Utility, % sanc. countries	other countries	Russia	Δ real consumption, % sanc. countries	other countries
Coal	-1.91	-0.07	0.08	-0.36	-0.14	0.03
Natural gas	-4.91	-0.37	0.39	0.21	-0.58	0.07
Crude oil	-7.39	0.06	0.3	0.44	-0.11	0.03
Refined products	-3.17	0	0.12	-1.54	-0.03	0.04
Natural gas and crude oil	-11.69	-0.33	0.69	1.35	-0.68	0.07
Natural gas, crude oil and refined products	-15.43	-0.33	0.85	0.44	-0.72	0.09
Natural gas, crude oil, refined products and coal	-16.82	-0.42	0.91	0.58	-0.87	0.1

Note: This table reports results for the counterfactual simulations of the embargo on exports of fossil fuels from Russia to a larger group of countries. The reported values are in percentage points of the changes. The simulations are based on GTAP data for 2017.

OECD countries, and a combined group of all these countries in Table 7, Table 8, and Table 9. These tables yield four main observations.

Firstly, while the coalition of G7 countries exerts the most substantial impact on Russia through a separate ban on natural gas, other coalitions have a more pronounced effect through a separate ban on crude oil. This distinction arises from the specific sourcing of natural gas involving Germany and other European countries within the G7 group. Secondly, the combined embargo on the above fuels significantly affects Russian welfare, resulting in a loss of 12.26% for the EU coalition. The inclusion of OECD countries deepens this loss to 16.57%. Although the joint coalition of G7, EU, and OECD countries does not yield a significant difference, this implies that a larger coalition of sanctioning countries yields a more detrimental impact on Russia's economy.

Thirdly, the sanctioning countries experience the most considerable loss within the EU coalition (3.25%). This is primarily because the EU acts as a net importer of fossil energy from Russia. Other coalitions generate a lower average loss for sanctioning countries (approximately 0.4%), concealing the presence of gains and losses across their fuel producers and buyers. Lastly, on average, the countries imposing no sanctions benefit more from larger coalitions. Their welfare gain averages 0.91% with the largest coalition of sanctioning countries.

In summary, this section has quantified the impact of broader scopes of fossil fuel sanctions and larger coalitions of sanctioning countries on the welfare and real consumption of the sanctioned country. We conclude that an EU-wide or OECD-wide embargo significantly impacts Russia's economy. The analysis has also demonstrated the negative effects on the sanctioning countries and highlighted the potential gains for non-aligned countries resulting from the trade restrictions. The EU coalition negatively impacts about 12% of Russian welfare at the welfare cost of about 3% in EU welfare and gain of about 0.6% elsewhere.

We now turn to a more detailed welfare comparison between countries.

4.2.3 Country comparison

We now delve into our counterfactual results for specific countries. For the sake of conciseness, we focus on the joint embargo on gas, crude oil, and refined products of coal and oil, and the largest sanctioning coalition, encompassing all G7, EU, and OECD countries (similar to Table 9).

Table 10 shows the ranking of changes in welfare and real consumption for each country within our dataset. Columns 1 to 3 highlight countries experiencing positive welfare changes, while Columns 4 to 6 encompass those with negative changes. As anticipated, countries with substantial fossil oil and gas production, such as Norway and Qatar, emerge as strong gainers. Real consumption also experiences notable increases in these nations. For example, Norway demonstrates a significant welfare boost of 11.98%, attributed to its status as a major oil producer on the European continent with the capacity to readily substitute Russian fossil energy. Canada, the USA, and the UK also benefit, albeit to a lesser extent (less than 1%), leveraging their positions in the global energy market.

Examining Table 10 reveals that the number of losers is smaller than that of gainers. Besides Russia, the sanctioning countries emerge as net losers in the face of the joint embargo. A noteworthy example is Latvia, Bulgaria, Slovakia, Hungary, and Czechia, each experiencing welfare losses ranging from 37.09% to 18.87%, surpassing even Russia's loss. In this model, smaller European economies situated at the border of the sanctioned country incur more substantial losses due to the higher costs associated with substituting their fossil fuel supplies away from Russia. This is the case of the above EU countries but also Greece, Poland, and Turkey, amongst others. European countries positioned farther from Russia, such as France, Spain, and Portugal, undergo lower losses. Interestingly, despite reports of intense stresses on their fuel supplies, Germany and the Netherlands incur welfare losses of a small amplitude (approximately 3%) compared to the EU countries neighboring Ukraine and Russia.

We now break down our results by country and sector for specific countries.

Table 10: Outcomes of embargo on exports of fossils from Russia to 44 countries

Countries	Total utility	Real consumption	Countries	Total utility	Real consumption
Norway	11.98	0.76	Latvia	-37.09	-24.02
Qatar	11.12	2.82	Bulgaria	-32.45	-20.57
Nigeria	7.06	1.06	Slovakia	-25.98	-15.08
Kazakhstan	6.28	0.90	Hungary	-19.11	-11.60
Iran	5.38	0.25	Czechia	-18.87	-10.61
Azerbaijan	4.93	0.13	Russia	-16.82	0.58
Bahrain	2.76	0.85	Greece	-13.01	-9.48
Saudi Arabia	2.25	0.25	Estonia	-10.48	-6.59
Egypt	2.15	-0.10	Lithuania	-9.32	-6.15
Colombia	1.55	-0.00	Finland	-8.58	-4.70
Tunisia	1.17	-0.50	Slovenia	-7.64	-3.79
Australia	1.13	0.01	Poland	-7.36	-4.83
United Arab Emirates	1.12	0.33	Austria	-6.93	-3.04
Côte d'Ivoire	0.95	-0.20	Turkey	-6.44	-3.62
Mexico	0.88	-0.21	Italy	-5.80	-2.87
Indonesia	0.82	0.02	Belarus	-3.01	2.34
Denmark	0.81	-0.61	Germany	-2.87	-1.50
Canada	0.72	-0.07	Netherlands	-2.79	-3.59
ROW	0.70	0.00	Georgia	-1.90	-0.40
Kenya	0.59	0.09	Belgium	-1.58	-1.07
United States	0.57	0.03	South Korea	-1.44	-0.86
Benin	0.57	0.08	Luxembourg	-1.43	-0.60
Senegal	0.54	-0.12	Kyrgyzstan	-1.43	-0.59
India	0.54	0.11	Armenia	-1.22	0.13
United Kingdom	0.52	-0.20	Ukraine	-1.10	-9.80
South Africa	0.51	-0.04	Malta	-1.06	-0.78
El Salvador	0.51	0.03	Cyprus	-0.92	-0.51
New Zealand	0.50	-0.00	France	-0.87	-0.50
Malaysia	0.50	-0.10	Paraguay	-0.81	-0.44
Singapore	0.49	0.11	Portugal	-0.45	-0.35
Ghana	0.48	0.01	Japan	-0.37	-0.32
Ecuador	0.47	-0.04	Spain	-0.33	-0.15
Guatemala	0.47	0.04	Croatia	-0.33	-0.98
Dominican Republic	0.46	0.01	Burkina Faso	-0.16	-0.26
Ethiopia	0.45	0.07	Sweden	-0.01	-0.15
Tanzania	0.45	0.05			
Thailand	0.44	0.05			
Hong Kong	0.44	0.02			
Sri Lanka	0.44	0.04			
Philippines	0.41	-0.00			
Peru	0.41	0.03			
Brazil	0.40	0.00			
Pakistan	0.36	-0.03			
China	0.36	0.06			
Uganda	0.35	0.05			
Morocco	0.34	0.16			
Costa Rica	0.32	0.00			
Oman	0.31	0.35			
Argentina	0.30	-0.01			
Panama	0.29	-0.03			
Albania	0.26	-0.23			
Ireland	0.24	-0.11			
Uruguay	0.20	0.03			
Chile	0.19	-0.04			
Vietnam	0.18	-0.13			
Bangladesh	0.17	-0.01			
Israel	0.12	-0.01			
Switzerland	0.04	-0.15			

Note: This table reports results for the counterfactual simulations for individual countries of the embargo on exports of fossil fuels from Russia to a group of 44 countries: G7, OECD, EU. We also assume no trade between Ukraine and Russia. The reported values are in percentage points of the changes. The simulations are based on GTAP data for 2017.

4.2.4 Germany

Over the past decades, Germany has significantly increased its dependency on Russian fossil fuels. In particular, since the 1990s, Germany has increased its natural gas supply from Russia through pipeline networks crossing Eastern European countries like Belarus, Poland, and Ukraine.[9] This was part of Germany's green energy strategy, compatible with the fight against climate change and the decision to phase out nuclear energy production following the Fukushima nuclear plant disaster in 2011. Consequently, in 2022, Germany was hesitant to participate in the EU's ban on Russian gas, as the coalition bloc opposing Ukraine's invasion prepared a new set of sanctions.[10] Germany therefore presents an instructive case of a country imposing sanctions while needing to balance the benefits of its external policy against the costs to its internal economy. In this subsection, we detail the economic channels of embargoes, highlighting the nature, origin, and destination of the traded goods that most significantly impact the country's welfare.

Table 11 and Table 12 show the contributions of changes in imports and exports by sector and trade partner for Germany. The embargoes carry on the four fossil fuels discussed above with a coalition of all G7, EU, and OECD countries. The tables rank the sector-partner pairs according to the change in trade value. Panels A and B respectively present the most important trade losses and gains. The columns present the initial values of the trade flows (third and fourth) and the changes in value, price, and volume, expressed as percentages of the pre-embargo values (fifth to eighth columns). The last column shows the impact of the changes in each trade flow value as a percentage of the German income.

Germany serves as a notable example of a sanctioning country, experiencing a 2.87% trade loss. The import of Russian crude oil decreases by USD $13,697$ million, accounting for a trade loss equivalent to 0.81% of German income. The import of Russian natural gas falls by USD $10,250$ million, representing a 0.6% reduction in income. Smaller declines are observed in Russian imports of coal and refined products of coal and oil, with drops of USD $4,772$ million and USD $3,038$ million, respectively, equivalent to 0.28% and 0.18% of income. These changes represent the direct effects of sanctions. Indirect effects manifest as increases in German prices for these products. Nevertheless, such price increases are below the percentage point, except for 'petroleum and coal products', which

[9]The German government promoted the construction of the Nord Stream 1 pipeline directly from Russia, which was completed and became operational in 2011. It also supported the construction of Nord Stream 2, which was completed in 2022 but rapidly suspended after Russia recognized Donetsk and Luhansk republics.

[10]Reuters, April 4, 2022.

rise by 7%. This quantitative approach indeed describes a long-run equilibrium that smooths the short-term effects of the sudden disruption of fuel supplies that has been witnessed in 2022. Finally, fossil fuel prices within Russia drop by a little bit more than 5%, which does not give evidence of strong long-term impact of the embargoes on Russian resource values.

After the embargoes, Germany shifts its fuel supplies to other countries. Neighboring EU countries are expected to play a significant role in this transformation. Panel B of Table 11 shows that Germany substitutes about two-thirds of its gas imports from Norway and the Netherlands. Norway, a key European energy supplier, permits Germany to increase its gas import volumes by 128.36%, contributing to a 134.25% rise in import value. Nevertheless, as these gas producers face higher demands, their production prices also increase by one or two percentage points. These two producers help Germany restore 0.54% out of the 0.60% of its equivalent income loss due to the gas embargo.

By contrast, the model predicts that Germany will substitute its oil imports from a more diversified set of producers. Panel B indeed reports the U.K., Nigeria, Kazakhstan, Norway, Egypt, and the USA as top contributors. Those producers allow Germany to restore 0.57% of its 0.81% trade loss (in equivalent income). Although these producers sell their oil at higher prices, the predicted increases in production prices are modest, amounting to fractions of a percentage point. The difference with the gas sector can be explained by the larger network of oil suppliers and the different transport infrastructures, which make oil transport costs less dependent on the distance between producers and consumers.

The fuel supplies and prices alter other German import sectors. Table 11 shows that this occurs mainly for the chemical products that are oil derivative products and are impacted by the higher oil costs in the EU (see panel A). The most important import reductions come from neighboring (or very close) countries like the Netherlands, Poland, Austria, Czechia, and Italy where chemical product prices rise between 3 and 7%.

As the fossil fuel embargoes alter energy prices, they also change countries' export positions. Panel A of Table 12 describes the German sectors that reduce their export volumes. Chemical products are the most impacted German goods, as their production prices rise by 2.94%. Machinery, motor vehicles, and transport equipment are also negatively affected. It should be noted that although these goods are not subject to the embargoes, their increased costs adversely impact Russia.

The value of the German reduction in exports to Russia, as shown in Panel A, amounts to about USD 6 billion, which is significant compared to the German reduction of fossil fuel imports of USD 31 billion (Panel A of Table 11). This may be considered as a second penalty to the belligerent country.

Finally, Panel B of Table 12 reveals that Germany has increased its exports of manufactured goods to the USA, Qatar, and Norway. This increase can be attributed to higher demand for German manufactured goods in fossil fuel-producing countries. Additionally, China has shown an increased demand for machinery and equipment. This trend is explained by slightly lower production prices, or smaller increases in those prices, for these goods. However, it should be noted that the export losses are much larger than the gains.

To summarize, this analysis indicates that, in the long run following the embargoes, Germany is expected to recover its gas supply from neighboring producers and its oil supplies from a variety of countries. Gas prices rise significantly more than oil prices. German chemical products and their prices are strongly affected. Germany experiences a notable decline in its exports of chemical products, machinery, transport equipment, and motor vehicles, particularly to Russia. However, some German manufacturing sectors see an increase in exports to certain fossil fuel-producing countries and to countries experiencing higher price rises in their manufacturing output.

4.2.5 Other countries

Similar country-specific studies can be conducted using this quantification model. While they are not detailed in this paper, we identify the special cases of the USA, China, and Ukraine. For more information on these, the reader is referred to Appendix C.

In a nutshell, the USA holds a unique position due to its role as the leader of the NATO defense organization, its firm stances for and against the belligerents, and its fossil fuel production. The quantitative model predicts that the USA benefits from the embargoes on Russian fossil fuels, gaining 0.57% in total utility. The embargoes lead to a reduction in existing imports of petroleum and coal products, resulting in a trade loss equivalent to 0.44% of its income. However, this loss is offset by improved export positions.

China holds a different position as a major global trade partner, characterized by its substantial energy needs and nuanced stances on the Russia-Ukraine conflict. The model predicts that China also becomes a beneficiary from the fossil fuel embargoes, gaining 0.36% in total utility terms.

Following the embargoes, China increases its Russian oil imports by USD 16 billion, to the detriment of other oil producers. Additionally, it boosts imports of Russian metals, wood products, chemicals, and food items. The shifts in world prices lead to increased Chinese exports in sectors such as computers, electronics, manufactured goods, machinery, and more.

In this paper, we have assumed that trade between Russia and Ukraine was already disrupted before the sanctions, representing economic harm to the latter. It is pertinent to further inquire whether the Russian fossil fuel embargoes also adversely affect Ukraine. The quantitative model indicates that Ukraine experiences further losses due to the embargoes, with a utility drop of 1.10%. In particular, the model predicts drops in Ukraine's imports of chemical and refined products from neighboring economies like Germany, Poland, Hungary, and Lithuania.

Table 11: Changes in imports to Germany

Sector	Origin	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	ΔP_{Origin}, %	$\Delta P_{Germany}$, %	$\Delta Volume$, %	Contribution to total, %
				Panel A: Largest negative changes in imports					
Oil	Russia	13,697	1.24	-13,697	-100.00	-5.25	0.36	-100.00	-0.81
Gas	Russia	10,252	0.93	-10,250	-99.97	-6.06	0.73	-99.97	-0.60
Refined products	Russia	4,772	0.43	-4,772	-100.00	-6.03	7.00	-100.00	-0.28
Coal	Russia	3,039	0.28	-3,038	-99.99	-6.94	-0.14	-99.99	-0.18
Chemical products	Netherlands	9,805	0.89	-1,590	-16.22	3.48	2.94	-19.04	-0.09
Chemical products	Poland	3,466	0.31	-843	-24.33	4.84	2.94	-27.83	-0.05
Paper products, publishing	Finland	3,231	0.29	-746	-23.10	4.33	1.23	-26.29	-0.04
Chemical products	Austria	2,480	0.22	-672	-27.10	5.34	2.94	-30.79	-0.04
Chemical products	Italy	4,938	0.45	-632	-12.80	2.96	2.94	-15.31	-0.04
Chemical products	Czechia	1,418	0.13	-554	-39.04	7.77	2.94	-43.43	-0.03
All other	All other	805,456	72.30	-24,627	-3.06			-3.75	-1.45
				Panel B: Largest positive changes in imports					
Gas	Norway	4,839	0.44	6,497	134.25	2.58	0.73	128.36	0.38
Oil	United Kingdom	4,417	0.40	2,976	67.38	0.54	0.36	66.48	0.18
Gas	Netherlands	1,941	0.18	2,663	137.22	1.29	0.73	134.20	0.16
Oil	Nigeria	3,458	0.31	2,357	68.17	0.50	0.36	67.33	0.14
Oil	Kazakhstan	3,732	0.34	2,126	56.96	1.14	0.36	55.19	0.13
Metals nec	Russia	579	0.05	1,731	298.98	-9.33	1.16	340.03	0.10
Oil	Norway	6,331	0.57	1,718	27.13	3.12	0.36	23.29	0.10
Oil	Egypt	1,570	0.14	1,125	71.65	0.31	0.36	71.11	0.07
Oil	United States	1,109	0.10	779	70.24	0.39	0.36	69.59	0.05
Chemical products	Russia	442	0.04	505	114.27	-8.21	2.94	133.45	0.03
All other	All other	213,144	19.05	10,959	5.14			4.50	0.65

Note: This table provides information on the post-embargo adjustment of the imports to Germany. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values and percentages for shares.

Table 12: Changes in exports from Germany

Sector	Destination	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	$\Delta P_{Dest.}$, %	$\Delta P_{Germany}$, %	$\Delta Volume$, %	Contribution to total, %
		Panel A: Largest negative changes in exports							
Chemical products	Russia	5,489	0.50	-2,206	-40.18	-8.21	2.94	-34.83	-0.13
Chemical products	China	9,404	0.85	-1,545	-16.43	0.38	2.94	-16.74	-0.09
Machinery and equipment nec	Russia	7,730	0.70	-1,495	-19.34	-8.43	-0.06	-11.92	-0.09
Motor vehicles and parts	Russia	5,238	0.47	-1,293	-24.69	-5.93	0.23	-19.94	-0.08
Transport equipment nec	Russia	2,825	0.26	-1,279	-45.26	-8.41	-0.00	-40.24	-0.08
Chemical products	France	11,504	1.04	-1,182	-10.28	1.34	2.94	-11.46	-0.07
Chemical products	Belgium	9,124	0.83	-1,130	-12.38	1.27	2.94	-13.47	-0.07
Chemical products	United States	7,289	0.66	-1,104	-15.14	0.67	2.94	-15.71	-0.07
Chemical products	Netherlands	5,950	0.54	-996	-16.75	3.48	2.94	-19.55	-0.06
Chemical products	Italy	8,700	0.79	-961	-11.04	2.96	2.94	-13.60	-0.06
All other	All other	463,448	41.62	-29,058	-6.27			-6.96	-1.71
		Panel B: Largest positive changes in exports							
Motor vehicles and parts	United States	16,476	1.49	522	3.17	0.55	0.23	2.60	0.03
Machinery and equipment nec	Qatar	1,817	0.16	470	25.85	5.21	-0.06	19.62	0.03
Machinery and equipment nec	United States	14,389	1.30	424	2.95	0.56	-0.06	2.38	0.02
Machinery and equipment nec	China	19,609	1.78	402	2.05	0.36	-0.06	1.68	0.02
Motor vehicles and parts	China	18,444	1.67	328	1.78	0.37	0.23	1.40	0.02
Motor vehicles and parts	Norway	2,641	0.24	327	12.39	5.17	0.23	6.86	0.02
Motor vehicles and parts	United Kingdom	19,273	1.75	288	1.49	0.66	0.23	0.83	0.02
Basic pharmaceutical products	United States	8,309	0.75	284	3.42	0.59	0.15	2.81	0.02
Computer, electronic and optical products	China	13,858	1.26	250	1.80	0.38	0.09	1.42	0.01
Gas	Czechia	10	0.00	248	2374.02	5.83	0.73	2237.69	0.01
All other	All other	452,603	40.38	10,528	2.33			1.40	0.62

Note: This table provides information on the post-embargo adjustment of the exports from Germany. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values, and percentages for shares.

5 Concluding remarks

In this paper, we explore a Ricardian trade model to assess the long-run impacts of potential sanctions against Russian fossil fuels on international trade patterns, welfare, and economic activities. To achieve this, we utilize the GTAP11-a database to quantify Caliendo and Parro (2015)'s model, encompassing 92 countries and 65 tradeable and non-tradeable sectors. We cross-validate our models against the existing literature on Brexit and the U.S.-China trade war. Subsequently, we conduct and analyze a series of counterfactual scenarios involving embargoes on Russian exports of coal, gas, crude oil, and refined products of coal and oil. We examine the effects of different combinations of banned sectors and various coalitions of sanctioning countries.

We derive several conclusions regarding the effects of such trade sanctions. First, the most effective embargo is that on Russian crude oil, followed in effectiveness by sanctions on Russian refined products, then, gas and coal. Second, a broader coalition of sanctioning countries leads to a more substantial negative impact on Russia's welfare and economic activity, while also resulting in lower average losses for the sanctioning countries themselves. A coalition formed by OECD countries appears to inflict the most significant damage on the sanctioned belligerent. The joint embargo on all Russian fossil fuels by the coalition of OECD countries diminishes the Russian welfare by more than 16%. Extending the coalition beyond these countries does not seem necessary. Finally, the embargoes significantly harm Eastern European countries that incur percent welfare losses of double digits. In the Western European part, Germany loses more than three percent of its welfare due to the disruption of its strong energy supplies from Russia.

Policymakers may consider the present results as part of their broad analysis regarding trade embargoes. We believe that our findings contribute to the most recent literature on economic sanctions.

References

Berlingieri, G., H. Breinlich, and S. Dhingra, "The Impact of Trade Agreements on Consumer Welfare—Evidence from the EU Common External Trade Policy," *Journal of the European Economic Association*, 2018, *16* (6), 1881–1928.

Bevington, M., H. Huang, A. Menon, J. Portes, J. Rutter, and T. Sampson, "The economic impact of Boris Johnson's Brexit proposals," Technical Report, Centre for Economic Performance, LSE 2019.

Bouet, A., Y. Decreux, L. Fontagne, S. Jean, and D. Laborde, "A Consistent, Ad-Valorem Equivalent Measure of Applied Protection Across the World: The MAcMap-HS6 Database," *SSRN Electronic Journal*, 2004.

Caliendo, L. and F. Parro, "Estimates of the Trade and Welfare Effects of NAFTA," *The Review of Economic Studies*, 2015, *82* (1), 1–44.

Chowdhry, Sonali, Julian Hinz, Katrin Kamin, and Joschka Wanner, "Brothers in arms: The value of coalitions in sanctions regimes," 2023.

Costinot, A. and A. Rodriguez-Clare, "Trade Theory with Numbers: Quantifying the Consequences of Globalization," in "Handbook of International Economics," Elsevier, 2014, pp. 197–261.

Crozet, M. and J. Hinz, "Friendly fire: the trade impact of the Russia sanctions and counter-sanctions," *Economic Policy*, 2020, *35* (101), 97–146.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum, "Global rebalancing with gravity: Measuring the burden of adjustment," *IMF Staff Papers*, 2008, *55* (3), 511–540.

Dhingra, S., H. Huang, G. Ottaviano, J. Paulo Pessoa, T. Sampson, and J. Van Reenen, "The costs and benefits of leaving the EU: trade effects," *Economic Policy*, 2017, *32* (92), 651–705.

Dreger, C., K.A. Kholodilin, D. Ulbricht, and J. Fidrmuc, "Between the hammer and the anvil: The impact of economic sanctions and oil prices on Russia's ruble," *Journal of Comparative Economics*, 2016, *44* (2), 295–308.

Fajgelbaum, P.D., P.K. Goldberg, P.J. Kennedy, and A.K. Khandelwal, "The Return to Protectionism," *The Quarterly Journal of Economics*, 2020, *135* (1), 1–55.

Felbermayr, G., J. Groschl, and I. Heiland, "Complex Europe: Quantifying the cost of disintegration," *Journal of International Economics*, 2022, *138*, 103647.

_ , _ , and M. Steininger, "Quantifying Brexit: from ex post to ex ante using structural gravity," *Review of World Economics*, 2022, *158* (2), 401–465.

Feyrer, James, "Distance, trade, and income-the 1967 to 1975 closing of the suez canal as a natural experiment," Technical Report, National Bureau of Economic Research 2009.

Fontagné, L., H. Guimbard, and G. Orefice, "Tariff-based product-level trade elasticities," *Journal of International Economics*, 2022, *137*, 103593.

Haidar, J.I., "Sanctions and export deflection: evidence from Iran," *Economic Policy*, 2017, *32* (90), 319–355.

Hausmann, Ricardo, Ulrich Schetter, and Muhammed Yildirim, "On the design of effective sanctions: The case of bans on exports to Russia," *CID Faculty Working Paper Series*, 2022.

Heilmann, K., "Does political conflict hurt trade? Evidence from consumer boycotts," *Journal of International Economics*, 2016, *99*, 179–191.

Hinz, J. and E. Monastyrenko, "Bearing the cost of politics: Consumer prices and welfare in Russia," *Journal of International Economics*, 2022, *137*, 103581.

Imbs, Jean and Laurent Pauwels, "An empirical approximation of the effects of trade sanctions with an application to Russia," *Economic Policy*, 2023, p. eiad027.

Irwin, D.A., "The Welfare Cost of Autarky: Evidence from the Jeffersonian Trade Embargo, 1807-09," *Review of International Economics*, 2005, *13* (4), 631–645.

O'Rourke, K.H., "War and welfare: Britain, France, and the United States 1807 14," *Oxford Economic Papers*, 2007, *59*, i8–i30. Supplement 1.

Walker, James T, "Voluntary export restraints between Britain and Japan: The case of the UK car market (1971–2002)," *Business History*, 2017, *59* (1), 35–55.

A Equilibrium in relative changes

In this paper, we study the implementation of trade embargoes as shocks in bilateral trade costs. Using the exact hat algebra as proposed by Dekle et al. (2008), we define $\widehat{x} = x'/x$, where x' stands for the value of variable x after the shock. Factor price proportionality imposes $\widehat{v}_n = \widehat{w}_n$. Changes in input bundle costs, price indices, and bilateral trade shares are given by

$$\widehat{c}_n^j = (\widehat{w}_n)^{\gamma_n^{lj} + \gamma_n^{mj}} \prod_k \left(\widehat{P}_n^k\right)^{\gamma_n^{k,j}}, \tag{A1}$$

$$\widehat{P}_n^j = \left(\sum_i \pi_{ni}^j \left(\widehat{\kappa}_{ni}^j \widehat{c}_i^j\right)^{-\theta^j}\right)^{-1/\theta^j}, \tag{A2}$$

$$\widehat{\pi}_{ni}^j = \left(\frac{\widehat{c}_i^j \widehat{\kappa}_{ni}^j}{\widehat{P}_n^j}\right)^{-\theta^j}. \tag{A3}$$

Counterfactual values of costs, prices, and trade-flow share are given by $c_n^{j\prime} = \widehat{c}_n^j c_n^j$, $P_n^{j\prime} = \widehat{P}_n^j P_n^j$, and $\pi_{ni}^{j\prime} = \widehat{\pi}_{ni}^j \pi_{ni}^j$. Counterfactual expenditures solve the system of linear equations

$$X_n^{j\prime} = \alpha_n^j \left[\widehat{w}_n \left(w_n L_n + v_n M_n\right) + R_n' + D_n\right] + \sum_k \sum_i \gamma_n^{jk} \frac{\pi_{in}^{k\prime}}{1 + \tau_{in}^{k\prime}} X_i^{k\prime} \tag{A4}$$

where $R_n' = \sum_j \sum_i \tau_{ni}^{j\prime} X_n^{j\prime} \frac{\pi_{ni}^{j\prime}}{1+\tau_{ni}^{j\prime}}$. The counterfactual trade balance is given by

$$\sum_j \sum_i \frac{\pi_{ni}^{j\prime}}{1 + \tau_{ni}^{j\prime}} X_n^{j\prime} = D_n + \sum_j \sum_i \frac{\pi_{in}^{j\prime}}{1 + \tau_{in}^{j\prime}} X_i^{j\prime}. \tag{A5}$$

For a given change $\widehat{\kappa}_{ni}^j$ and $\widehat{\tau}_{ni}^j$, the equilibrium is found by the following algorithm: (1) set the vector $\widehat{w}_n$ to one, (2) jointly compute $\widehat{c}_n^j$ and $\widehat{P}_n^j$ using the baseline share π_{ni}^j in the system of $N * J$ non-linear equation (contraction algorithm works), (3) compute $\widehat{\pi}_{ni}^j$, (4) compute I_n' and $\pi_{ni}^{k\prime}$ solve for $X_n^{j\prime}$ in the linear system of $N * J$ equations (A4), (5) decrease $\widehat{w}_n$ if the LHS is larger than the RHS of (A5), and finally (6) repeat from (2) until convergence.

For the sake of clarity, we present some results for country aggregates in which we aggregate the welfare measures $W_n = I_n/P_n$ and $W_n' = I_n'/P_n'$. For a subset $\mathcal{N}$ of countries, the welfare change is expressed as

$$\widehat{W}_{\mathcal{N}} = \frac{\sum_{n\in\mathcal{N}} W_n'}{\sum_{i\in\mathcal{N}} W_i} = \sum_{n\in\mathcal{N}} \left(\frac{I_n/P_n}{\sum_{i\in\mathcal{N}} I_i/P_i}\right)\left(\frac{\widehat{I}_n}{\widehat{P}_n}\right) \tag{A6}$$

Similarly, the relative change in real consumption in the group of countries $\mathcal{N}$ aggregates as

$$\widehat{X}^{\mathsf{c}}_{\mathcal{N}} = \frac{\sum_{n\in\mathcal{N}} X_n^{c\prime}}{\sum_{i\in\mathcal{N}} X_i^{c}} = \sum_{n\in\mathcal{N}} \left(\frac{X_n/P_n}{\sum_{i\in\mathcal{N}} X_i/P_i} \right) \left(\frac{\widehat{X}_n}{\widehat{P}_n} \right). \tag{A7}$$

B Trade disruption between Ukraine and Russia.

In this appendix, we present the predicted welfare and real consumption effects of the trade disruption between Ukraine and Russia. Table B1 presents the counterfactual changes in welfare and economic activity when all trade tariffs between Ukraine and Russia are set to infinity. It shows that Ukraine incurs a 14.1% welfare loss that is much larger than the 0.41% Russian welfare loss. Welfare and economic activity in the EU, the USA, and China are not significantly altered by the trade disruption.

Table B1: Effect of trade disruption between Russia and Ukraine

Countries	Total utility	Real consumption	Countries	Total utility	Real consumption
Nigeria	0.55	0.01	Ukraine	-14.02	-8.61
Belarus	0.33	0.82	South Korea	-0.54	0.01
Oman	0.14	0.02	Benin	-0.47	-0.00
Lithuania	0.12	0.13	Senegal	-0.44	-0.01
Qatar	0.08	0.00	Russia	-0.41	-0.21
Estonia	0.08	0.01	Iran	-0.41	0.01
Latvia	0.07	0.01	Egypt	-0.32	0.02
Norway	0.07	-0.01	Kenya	-0.27	0.02
Cyprus	0.04	0.01	Ghana	-0.27	-0.01
Armenia	0.04	0.06	Kyrgyzstan	-0.24	0.68
Luxembourg	0.04	0.02	Uganda	-0.16	0.01
Indonesia	0.04	-0.00	Tanzania	-0.16	0.01
Finland	0.04	0.01	Azerbaijan	-0.16	-0.00
Belgium	0.03	0.02	Bahrain	-0.15	0.00
Sweden	0.03	0.00	Vietnam	-0.15	0.00
Hong Kong	0.03	0.01	Ethiopia	-0.15	0.01
Netherlands	0.03	0.01	Burkina Faso	-0.15	0.01
Australia	0.03	-0.01	Sri Lanka	-0.14	0.00
New Zealand	0.02	-0.00	Tunisia	-0.14	0.05
Austria	0.02	0.00	United Arab Emirates	-0.13	0.01
Germany	0.02	0.01	ROW	-0.13	0.00
Chile	0.02	0.00	Côte d'Ivoire	-0.11	-0.00
France	0.02	0.00	Paraguay	-0.11	-0.01
Italy	0.02	0.01	Guatemala	-0.10	0.03
Portugal	0.02	0.01	Malaysia	-0.09	-0.00
Ireland	0.02	0.00	Panama	-0.09	0.01
Denmark	0.02	-0.00	South Africa	-0.08	0.00
Spain	0.02	0.01	Bulgaria	-0.07	-0.02
Czechia	0.02	0.00	Pakistan	-0.07	0.01
United Kingdom	0.01	0.01	Uruguay	-0.07	-0.00
China	0.01	0.00	Kazakhstan	-0.06	0.05
El Salvador	0.01	0.01	Argentina	-0.06	-0.01
Peru	0.01	0.00	Ecuador	-0.05	-0.00
Hungary	0.01	0.01	Malta	-0.05	-0.02
Albania	0.01	-0.00	Dominican Republic	-0.04	0.01
Philippines	0.01	0.01	Thailand	-0.04	0.01
Slovenia	0.01	0.00	Colombia	-0.03	0.01
Slovakia	0.00	0.02	Costa Rica	-0.03	0.01
Greece	0.00	0.02	Bangladesh	-0.03	0.01
Mexico	0.00	0.01	Brazil	-0.02	-0.01
			Georgia	-0.02	0.02
			India	-0.02	0.02
			Turkey	-0.02	-0.00
			United States	-0.02	0.02
			Singapore	-0.02	0.01
			Poland	-0.01	-0.00
			Japan	-0.01	0.01
			Morocco	-0.01	0.01
			Croatia	-0.01	-0.01
			Israel	-0.01	0.02
			Canada	-0.01	0.01
			Switzerland	-0.00	0.00
			Saudi Arabia	-0.00	0.01

Note: This table reports counterfactual results for the scenario where the international trade between Russia and Ukraine is completely halted. The reported values are in percentage points of the changes. The simulations are based on GTAP data for 2017.

C Special country analyses

In this appendix, we report the predicted changes in trade flows in three countries of special interest: the USA, China, and Ukraine. The tables show the contributions of changes in imports and exports by sector and trade partner for those countries. The embargoes carry on the four fossil fuels discussed above with a coalition of all G7, EU, and OECD countries. The tables rank the sector-partner pairs according to the change in the ratios between their trade-flow values and their income. Panels A and B respectively present the ten most important losses and gains. The columns present the initial values of the trade flows (third and fourth) and the changes in value, price, and volume, expressed as percentages of the pre-embargo values (fifth to eighth columns). The last column shows the contribution of these changes as a percentage of the country's income.

Table C1: Changes in imports to Ukraine

Sector	Origin	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	ΔP_{Origin}, %	$\Delta P_{Ukraine}$, %	$\Delta Volume$, %	Contribution to total, %
				Panel A: Largest negative changes in imports					
Chemical products	Poland	760	1.79	-148	-19.46	4.84	-0.23	-23.18	-0.01
Refined products	Lithuania	321	0.76	-109	-33.84	9.53	-1.28	-39.60	-0.01
Chemical products	Hungary	152	0.36	-97	-63.58	16.02	-0.23	-68.61	-0.01
Chemical products	Germany	1,079	2.55	-76	-7.07	2.94	-0.23	-9.73	-0.00
Refined products	Poland	138	0.33	-60	-43.60	14.45	-1.28	-50.72	-0.00
Chemical products	Slovakia	58	0.14	-45	-77.27	23.23	-0.23	-81.56	-0.00
Rubber and plastic products	Hungary	209	0.49	-40	-19.36	3.87	0.26	-22.36	-0.00
Chemical products	Czechia	112	0.26	-39	-35.11	7.77	-0.23	-39.79	-0.00
Chemical products	Bulgaria	38	0.09	-33	-85.48	30.48	-0.23	-88.87	-0.00
Oil	Azerbaijan	116	0.27	-26	-22.48	2.02	-0.50	-24.01	-0.00
All other	All other	27,021	63.12	-1,455	-5.38			-6.13	-0.09
				Panel B: Largest positive changes in imports					
Refined products	Belarus	4,069	9.60	423	10.39	-4.85	-1.28	16.02	0.02
Chemical products	Belarus	334	0.79	195	58.40	-3.84	-0.23	64.72	0.01
Chemical products	China	683	1.61	90	13.23	0.38	-0.23	12.80	0.01
Motor vehicles and parts	Belarus	90	0.21	35	39.13	-3.77	-0.79	44.58	0.00
Rubber and plastic products	Belarus	96	0.23	33	34.69	-3.43	0.26	39.48	0.00
Chemical products	United States	265	0.63	28	10.65	0.67	-0.23	9.92	0.00
Chemical products	France	485	1.14	25	5.10	1.34	-0.23	3.71	0.00
Machinery and equipment nec	Belarus	149	0.35	23	15.24	-3.32	-0.92	19.20	0.00
Mineral products nec	Belarus	107	0.25	22	20.92	-4.01	-0.68	25.97	0.00
Wood products	Belarus	62	0.15	19	29.84	-3.29	-0.64	34.26	0.00
All other	All other	6,052	14.10	228	3.76			3.44	0.01

Note: This table provides information on the post-embargo adjustment of the imports to Ukraine. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values, and percentages for shares.

Table C2: Changes in exports from Ukraine

Sector	Destination	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	$\Delta P_{Dest.}$, %	$\Delta P_{Ukraine}$, %	$\Delta Volume$, %	Contribution to total, %
Panel A: Largest negative changes in exports									
Other Extraction	Slovakia	747	1.81	-269	-36.07	1.35	-0.96	-36.92	-0.02
Food products nec	Belarus	174	0.42	-44	-25.23	-3.50	-0.77	-22.52	-0.00
Ferrous metals	Belarus	261	0.63	-39	-15.14	-5.74	-1.13	-9.97	-0.00
Other Extraction	Belarus	96	0.23	-27	-27.84	-3.22	-0.96	-25.44	-0.00
Metals nec	Belarus	47	0.11	-23	-48.70	-5.34	-0.95	-45.81	-0.00
Paper products, publishing	Belarus	75	0.18	-22	-29.89	-3.48	-0.14	-27.36	-0.00
Ferrous metals	Bulgaria	436	1.06	-22	-5.00	5.32	-1.13	-9.80	-0.00
Other Extraction	Hungary	163	0.39	-19	-11.78	3.87	-0.96	-15.07	-0.00
Vegetable oils and fats	Belarus	169	0.41	-19	-11.15	-3.53	-0.79	-7.91	-0.00
Rubber and plastic products	Belarus	72	0.17	-17	-23.14	-3.43	0.26	-20.41	-0.00
All other	All other	7,343	17.65	-316	-4.30			-4.52	-0.02
Panel B: Largest positive changes in exports									
Other Extraction	China	1,569	3.80	192	12.27	0.33	-0.96	11.89	0.01
Ferrous metals	Italy	1,784	4.32	137	7.67	2.77	-1.13	4.76	0.01
Other Extraction	Austria	463	1.12	129	27.89	5.93	-0.96	20.72	0.01
Vegetable oils and fats	India	1,466	3.55	57	3.89	0.50	-0.79	3.37	0.00
Ferrous metals	Poland	701	1.70	52	7.35	2.89	-1.13	4.34	0.00
Ferrous metals	United States	781	1.89	49	6.23	0.57	-1.13	5.62	0.00
Other Extraction	ROW	319	0.77	49	15.25	0.58	-0.96	14.59	0.00
Ferrous metals	Turkey	1,213	2.94	44	3.60	2.10	-1.13	1.46	0.00
Gas	Hungary	3	0.01	42	1501.07	4.46	-0.49	1432.67	0.00
Other Extraction	Czechia	476	1.15	37	7.83	5.52	-0.96	2.19	0.00
All other	All other	22,935	54.96	1,233	5.38			4.27	0.07

Note: This table provides information on the post-embargo adjustment of the exports from Ukraine. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values and percentages for shares.

Table C3: Changes in imports to China

Sector	Origin	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	ΔP_{Origin}, %	ΔP_{China}, %	$\Delta Volume$, %	Contribution to total, %
				Panel A: Largest negative changes in imports					
Chemical products	South Korea	43,240	2.21	-2,535	-5.86	1.39	0.38	-7.15	-0.15
Oil	Saudi Arabia	22,942	1.17	-2,104	-9.17	0.69	0.24	-9.79	-0.12
Chemical products	Germany	9,404	0.48	-1,545	-16.43	2.94	0.38	-18.81	-0.09
Oil	ROW	21,852	1.11	-1,439	-6.58	0.43	0.24	-6.98	-0.08
Other Extraction	Australia	47,286	2.41	-1,376	-2.91	0.80	0.33	-3.68	-0.08
Chemical products	Japan	35,782	1.82	-835	-2.33	0.91	0.38	-3.22	-0.05
Oil	Iran	14,810	0.76	-759	-5.13	0.28	0.24	-5.39	-0.04
Oil	Oman	20,417	1.04	-636	-3.12	0.09	0.24	-3.20	-0.04
Oil	Brazil	11,695	0.60	-623	-5.33	0.30	0.24	-5.61	-0.04
Refined products	South Korea	7,723	0.39	-591	-7.66	2.42	-0.08	-9.84	-0.03
All other	All other	818,063	41.10	-16,524	-2.02			-2.98	-0.97
				Panel B: Largest positive changes in imports					
Oil	Russia	21,428	1.09	16,276	75.96	-5.25	0.24	85.70	0.96
Metals nec	Russia	780	0.04	2,273	291.40	-9.33	0.36	331.67	0.13
Wood products	Russia	1,612	0.08	2,192	136.01	-9.22	0.30	159.97	0.13
Other Extraction	Russia	1,043	0.05	1,260	120.79	-8.73	0.33	141.91	0.07
Chemical products	Russia	1,179	0.06	1,240	105.12	-8.21	0.38	123.47	0.07
Paper products, publishing	Russia	524	0.03	678	129.57	-9.26	0.38	153.01	0.04
Food products nec	Russia	986	0.05	569	57.65	-8.84	0.37	72.94	0.03
Forestry	Russia	1,589	0.08	410	25.78	-8.43	0.34	37.35	0.02
Machinery and equipment nec	Germany	19,609	1.00	402	2.05	-0.06	0.36	2.11	0.02
Refined products	Russia	1,346	0.07	354	26.27	-6.03	-0.08	34.37	0.02
All other	All other	857,667	43.43	6,781	0.79			-7.97	0.40

Note: This table provides information on the post-embargo adjustment of the imports to China. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values, and percentages for shares.

Table C4: Changes in exports from China

Sector	Destination	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	$\Delta P_{Dest.}$, %	ΔP_{China}, %	$\Delta Volume$, %	Contribution to total, %
				Panel A: Largest negative changes in exports					
Computer, electronic and optical products	Russia	11,034	0.56	-2,552	-23.13	-8.34	0.38	-16.14	-0.15
Machinery and equipment nec	Russia	8,730	0.45	-1,814	-20.78	-8.43	0.36	-13.48	-0.11
Wearing apparel	Russia	8,894	0.45	-1,580	-17.77	-8.23	0.38	-10.40	-0.09
Electrical equipment	Russia	5,672	0.29	-1,331	-23.47	-8.23	0.37	-16.60	-0.08
Chemical products	Russia	4,350	0.22	-1,180	-27.12	-8.21	0.38	-20.60	-0.07
Mineral products nec	Russia	2,934	0.15	-1,162	-39.61	-9.29	0.36	-33.42	-0.07
Metal products	Russia	4,068	0.21	-1,145	-28.15	-8.82	0.36	-21.20	-0.07
Manufactures nec	Russia	3,275	0.17	-958	-29.24	-8.36	0.33	-22.78	-0.06
Metals nec	Russia	1,435	0.07	-821	-57.18	-9.33	0.36	-52.78	-0.05
Food products nec	Russia	1,904	0.10	-725	-38.07	-8.84	0.37	-32.06	-0.04
All other	All other	436,624	21.86	-11,697	-2.68			-2.77	-0.69
				Panel B: Largest positive changes in exports					
Computer, electronic and optical products	United States	122,288	6.24	1,035	0.85	0.56	0.38	0.29	0.06
Manufactures nec	United States	40,104	2.04	625	1.56	0.57	0.33	0.98	0.04
Chemical products	South Korea	13,519	0.69	513	3.80	1.39	0.38	2.38	0.03
Machinery and equipment nec	Qatar	2,063	0.11	487	23.62	5.21	0.36	17.50	0.03
Chemical products	Japan	12,197	0.62	472	3.87	0.91	0.38	2.93	0.03
Chemical products	United States	13,266	0.68	450	3.39	0.67	0.38	2.70	0.03
Wearing apparel	Nigeria	2,761	0.14	404	14.64	4.85	0.38	9.34	0.02
Electrical equipment	United States	43,509	2.22	386	0.89	0.56	0.37	0.33	0.02
Wood products	Nigeria	827	0.04	345	41.71	5.17	0.30	34.75	0.02
Textiles	Nigeria	2,814	0.14	300	10.66	4.13	0.39	6.28	0.02
All other	All other	1,219,035	61.52	22,297	1.83			-1.55	1.31

Note: This table provides information on the post-embargo adjustment of the exports from China. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values, and percentages for shares.

Table C5: Changes in imports to United States

Sector	Origin	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	ΔP_{Origin}, %	ΔP_{USA}, %	$\Delta Volume$, %	Contribution to total, %
				Panel A: Largest negative changes in imports					
Refined products	Russia	7,499	0.39	-7,499	-100.00	-6.03	0.48	-100.00	-0.44
Chemical products	Germany	7,289	0.38	-1,104	-15.14	2.94	0.67	-17.56	-0.07
Oil	Russia	588	0.03	-588	-100.00	-5.25	0.39	-100.00	-0.03
Metals nec	Canada	28,509	1.47	-441	-1.55	0.59	0.54	-2.12	-0.03
Chemical products	Netherlands	1,874	0.10	-348	-18.56	3.48	0.67	-21.30	-0.02
Chemical products	Italy	2,053	0.11	-313	-15.25	2.96	0.67	-17.68	-0.02
Motor vehicles and parts	Mexico	77,700	4.01	-267	-0.34	0.61	0.55	-0.95	-0.02
Refined products	Finland	351	0.02	-233	-66.34	36.83	0.48	-75.40	-0.01
Refined products	Lithuania	923	0.05	-225	-24.36	9.53	0.48	-30.94	-0.01
Chemical products	France	5,460	0.28	-220	-4.03	1.34	0.67	-5.29	-0.01
All other	All other	461,342	23.51	-6,797	-1.47			-2.30	-0.40
				Panel B: Largest positive changes in imports					
Metals nec	Russia	782	0.04	2,307	295.09	-9.33	0.54	335.73	0.14
Oil	Canada	56,355	2.91	2,055	3.65	0.41	0.39	3.22	0.12
Ferrous metals	Russia	2,820	0.15	1,091	38.67	-8.48	0.57	51.53	0.06
Computer, electronic and optical products	China	122,288	6.31	1,035	0.85	0.38	0.56	0.46	0.06
Chemical products	Russia	827	0.04	895	108.27	-8.21	0.67	126.91	0.05
Motor vehicles and parts	Japan	40,361	2.08	697	1.73	0.38	0.55	1.34	0.04
Oil	Mexico	14,491	0.75	692	4.77	0.31	0.39	4.44	0.04
Manufactures nec	China	40,104	2.07	625	1.56	0.33	0.57	1.22	0.04
Motor vehicles and parts	Germany	16,476	0.85	522	3.17	0.23	0.55	2.94	0.03
Gas	Canada	34,584	1.79	497	1.44	0.40	0.37	1.04	0.03
All other	All other	1,013,861	51.67	14,934	1.47			0.98	0.88

Note: This table provides information on the post-embargo adjustment of the imports to United States. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values, and percentages for shares.

Table C6: Changes in exports from United States

Sector	Destination	Initial value	Initial share	$\Delta Value$	$\Delta Value$, %	$\Delta P_{Dest.}$, %	ΔP_{USA}, %	$\Delta Volume$, %	Contribution to total, %
				Panel A: Largest negative changes in exports					
Machinery and equipment nec	Russia	2,529	0.13	-542	-21.42	-8.43	0.56	-14.18	-0.03
Oil	China	8,517	0.44	-528	-6.20	0.24	0.39	-6.43	-0.03
Chemical products	Russia	1,716	0.09	-494	-28.77	-8.21	0.67	-22.40	-0.03
Computer, electronic and optical products	Russia	1,566	0.08	-374	-23.85	-8.34	0.56	-16.92	-0.02
Metals nec	Russia	577	0.03	-336	-58.21	-9.33	0.54	-53.92	-0.02
Computer, electronic and optical products	Netherlands	10,718	0.55	-335	-3.13	0.42	0.56	-3.53	-0.02
Motor vehicles and parts	Russia	1,105	0.06	-297	-26.87	-5.93	0.55	-22.26	-0.02
Metals nec	United Kingdom	16,104	0.83	-288	-1.79	0.64	0.54	-2.41	-0.02
Metals nec	China	15,281	0.79	-281	-1.84	0.36	0.54	-2.19	-0.02
Motor vehicles and parts	China	20,630	1.07	-240	-1.16	0.37	0.55	-1.53	-0.01
All other	All other	884,438	44.76	-11,415	-1.29			-2.74	-0.67
				Panel B: Largest positive changes in exports					
Oil	Poland	336	0.02	830	246.70	-0.32	0.39	247.82	0.05
Oil	Germany	1,109	0.06	779	70.24	0.36	0.39	69.63	0.05
Chemical products	Belgium	16,466	0.85	713	4.33	1.27	0.67	3.03	0.04
Machinery and equipment nec	Qatar	2,877	0.15	651	22.62	5.21	0.56	16.55	0.04
Refined products	Netherlands	2,098	0.11	645	30.73	7.09	0.48	22.07	0.04
Refined products	Turkey	2,792	0.14	484	17.35	4.36	0.48	12.45	0.03
Refined products	France	3,036	0.16	439	14.45	3.49	0.48	10.59	0.03
Chemical products	France	5,890	0.30	403	6.84	1.34	0.67	5.43	0.02
Chemical products	United Kingdom	6,143	0.32	387	6.31	1.25	0.67	4.99	0.02
Oil	Belgium	506	0.03	387	76.48	0.44	0.39	75.71	0.02
All other	All other	931,818	47.70	16,905	1.81			0.83	1.00

Note: This table provides information on the post-embargo adjustment of the exports from United States. The simulations are based on GTAP data for 2017. All data is denoted in millions of U.S. dollars for values, and percentages for shares.