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Special issue article
The impact of the Crimea annexation on agricultural trade: A structural gravity approach

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Abstract

We examine the impact of the 2014 Russian annexation of Crimea on global agricultural trade flows. Using a structural gravity model with a Poisson Pseudo Maximum Likelihood (PPML) estimator and intra-country sales, we differentiate the effects of the war from those of the sanctions on trade. We estimate conditional General Equilibrium PPML counterfactual scenarios and apply a "conventional two-step approach" to assess trade potential for Russia, Ukraine and European Union members. Our results suggest that while both Russia's and Ukraine's trade flows benefited during the post-annexation period, sanctions had a negative impact, with Russia experiencing more severe effects.

Keywords: structural gravity, GEPPML, trade potential, agricultural trade

JEL classification: F1, F14, F13, C00, Q17

1. Introduction

The war between Russia and Ukraine began in March 2014 when Russia invaded and annexed Ukraine's Crimean Peninsula. The annexation was met with widespread international condemnation and led to a protracted conflict in Eastern Ukraine, disrupting lives and livelihoods and significantly affecting the region's stability.

The war soon escalated into a broader geopolitical struggle, with economic warfare emerging as a critical dimension of the conflict, triggering severe socioeconomic repercussions. By 2015, Ukraine's gross domestic product (GDP) contracted by 16.4 per cent, prices rose by 68.2 per cent, unemployment and government debt surged and the local currency depreciated (Dabrowski, Domínguez-Jiménez and Zachmann, 2020). In addition to these economic shocks, the loss of human lives, widespread suffering, mass displacement, loss of land and productive capacity compounded the toll on Ukraine's economy. Decreased access to financial markets and strained external relations further deepened the crisis, contributing to a dynamic impact of the effects.

The supply shortages, the consequent increases in prices and the disruption of global value chains resulted in the diffusion of effects to global markets. Russian attacks on ports further hindered Ukraine's ability to export agricultural products to many foreign markets, exacerbating the diffusion of the effects across borders. Developing economies with close trade ties to Ukraine, such as Pakistan, which imports 49 per cent of its wheat from Ukraine; Lebanon, with 62 per cent; and Egypt, with 23 per cent (Gaulier and Zignago, 2010; FAO, 2022), were among the countries most affected.[1] The economic and trade sanctions imposed on Russia, along with the subsequent countermeasures adopted by Russia, further impacted external relations, trade flows, product prices and global value chains.

The increase in many staple commodity prices, the concurrent global inflation pressures and the likely impact on developing countries stress the need to re-examine the "lessons that history taught us." We study the impact of the 2014 annexation of the Crimean Peninsula and the ongoing war on agricultural trade. We concentrate on trade, as the impact on the free flow of goods is closely related with the ability to buffer disruptions caused by shocks to prices (Smith and Glauber, 2019). We concentrate on the agricultural sector because the armed conflict and the consequent disruptions, particularly to trade and agricultural commodity prices, are considered among the most important effects of the war (Goyal and Steinbach, 2023; WTO, 2023).

The existing literature on the Russo-Ukrainian war has utilized structural gravity models (Cheptea and Gaigné, 2020; Larch, Luckstead and Yotov, 2024), computable general equilibrium (GE) models (Boulanger *et al*., 2016; Kutlina-Dimitrova, 2017; Rose, Chen and Wei, 2023) and spatial equilibrium models (Devadoss and Ridley, 2024), among others. The literature has focused on commodity-specific effects of the war (Cheptea and Gaigné, 2020; Devadoss and Ridley, 2024; Larch, Luckstead and Yotov, 2024), the impact on food security (Lin *et al*., 2023), market volatility (Legrand, 2022), commodity prices (Steinbach, 2023), the impact of restrictions on mutual trade relations (Barron, 2022; Skvarciany, Jurevičienė and Vidžiūnaitė, 2020) and the impact of sanctions on trade (Crozet and Hinz, 2016; Crozet and Hinz, 2019; Cheptea

1 Price disruptions can have disproportionate effects on developing countries (Ivanic and Martin, 2014), as their subsistence caloric intake of basic food staples often depends heavily on imports.

and Gaigné, 2020; Felbermayr *et al*., 2020; Dai *et al*., 2021; Larch, Luckstead and Yotov, 2024).

We employ a structural gravity model (Anderson and van Wincoop, 2003) with intra-country sales (Heid, Larch and Yotov, 2021; Yotov, 2022) and the General Equilibrium Poisson Pseudo Maximum Likelihood (GEPPML) method (Anderson, Larch and Yotov, 2018) to assess the war's impact on agricultural trade. Our contribution to the literature has four distinct parts: first, we extend the structural gravity literature on the Russo-Ukrainian conflict by differentiating the effects of the war from those of the sanctions. Our study builds on the existing literature by Cheptea and Gaigné (2020) and Larch, Luckstead and Yotov (2024), broadening the analysis to include the dynamic effects of the conflict, while isolating the role of sanctions versus the war. Second, we contribute to the *ex post* estimation of how the conflict's effects on agricultural trade are transmitted to countries indirectly affected by the war. While most existing studies focus on the impact of sanctions on specific countries or agricultural products, we concentrate on third-country effects and aggregate agricultural trade values. Third, we investigate post-2014 changes in global trade capacity for agricultural products, drawing on the literature on trade potential. Specifically, we analyze the gap between maximum potential and realized exports of Russia, Ukraine and the European Union (EU) since the war began, offering a new perspective on the resulting trade reallocation. Finally, we contribute to the study of the impacts of large-scale disruptions in production and prices on agricultural trade. Our results inform discussions of policy implications and strategies to support the evolution of trade in turbulent times.

The next section (Section 2) discusses the impacts of the annexation of Crimea on prices, GDP and trade. Section 3 provides a review of the theory related to structural gravity literature, while Section 4 outlines the methodology. Sections 5–7 present the results, followed by a discussion on the effectiveness of the imposed sanctions, policy implications and the conclusions of this research.

2. Literature review: the Crimea annexation and gravity models

The events leading to the invasion began in November 2013, when Ukrainian President Yanukovych, under pressure from Russia, declined to sign a free trade agreement with the EU. The agreement was widely perceived as a move away from Eastern influences. The president's refusal to sign resulted in the Euromaidan protests (Revolution of Dignity), which ultimately led to the collapse of the existing regime. In March and June of 2014, the EU–Ukraine Association Agreement (AA) was finally signed, marking a pivotal moment in Ukraine's history by steering the country's policies and economy away from Eastern influences, while strengthening political, economic and legal ties with the EU. This shift toward Western standards provoked Russian retaliation, culminating in the 2014 invasion and annexation of Crimea (Dabrowski, Domínguez-Jiménez and Zachmann, 2020). The conflict continued in a state

of partial suspension, with intermittent exchanges of fire across ceasefire lines (Dabrowski, Domínguez-Jiménez and Zachmann, 2020), until February 2022, when rising geopolitical tensions led to further escalation, with Russia launching a full-scale invasion of Ukraine in an attempt to annex the Donetsk and Luhansk regions.[2]

Following the annexation of Crimea, the international community implemented diplomatic and economic measures, including sanctions and diplomatic condemnations. The USA and EU suspended negotiations with Russia on political and economic issues. Between February and March 2014, the EU froze assets, issued travel bans on officials and restricted trade, investments and tourism in Crimea. These measures were later amended with bans/sanctions on oil, gas, energy, technology, defense, finance and the banking sector. In August 2014, Russia retaliated with sanctions on food imports from the EU28, the USA, Canada, Norway and Australia, banning fruits, vegetables, meat, fish and dairy for an initial year. The embargo was extended in August 2015, June 2016 and June 2017. Additionally, Russia imposed trade restrictions on Ukraine before the EU–Ukraine AA's signing.[3] After its enactment in January 2016, Russia revoked its Commonwealth of Independent States (CIS) Free Trade Agreement with respect to Ukraine and banned Ukrainian agri-food imports (Cenusa *et al*., 2014; Boyko *et al*., 2024).

The war and the resulting sanctions led to production shortages, disruptions in global value chains and increased uncertainty, collectively triggering an immediate increase in prices. Goyal and Steinbach (2023) suggest that 9 weeks after the war began, future prices for agricultural commodities were 16 per cent higher compared to a no-war counterfactual. Carter and Steinbach (2023) further found that following Russia's invasion of Ukraine, future prices for wheat rose by 30 per cent, while futures prices for corn increased by 10 per cent. Wheat prices rose by approximately 2 per cent in every country except Ukraine, where they fell by 27 per cent (Devadoss and Ridley, 2024).

The price increases prompted the establishment of the EU Solidarity Lanes in May 2022 and the Black Sea Grain Initiative in July 2022. These initiatives aimed to mitigate the impact of the war by resuming and expanding agricultural commodity shipments via road, rail and the Danube (Carter and Steinbach, 2023) and by lifting the Russian blockade of ports to provide safe passage for

2 While Russia never articulated a consistent set of war aims, the annexation of Donetsk and Luhansk regions appeared to be a focal point of its actions. However, initial troop deployments and advances toward Kyiv suggest a broader strategic intent, with the annexation possibly serving as a pretext to capture additional territories, including the Ukrainian capital. Russian military and political leaders articulated objectives for the war against Ukraine, but these were often "inchoate, contradictory, and inconsistent" throughout 2022 (Charap and Hoolynska, 2024), reflecting an effort by the Kremlin to keep its options open regarding how to proceed and what terms to accept for a settlement. This ambiguity aligns with broader patterns in Russia's tactics, which persist due to their flexibility and low cost, serving to enhance its influence regardless of any specific end goal (Hurak and Anieri, 2020).

3 The agreement included provisions for a Deep and Comprehensive Free Trade Area. Before the November 2013 summit in Vilnius for the signing of the AA/DCFTA, Russia imposed punitive trade measures against Ukraine, mostly on agro-food products (Cenusa *et al*., 2014)

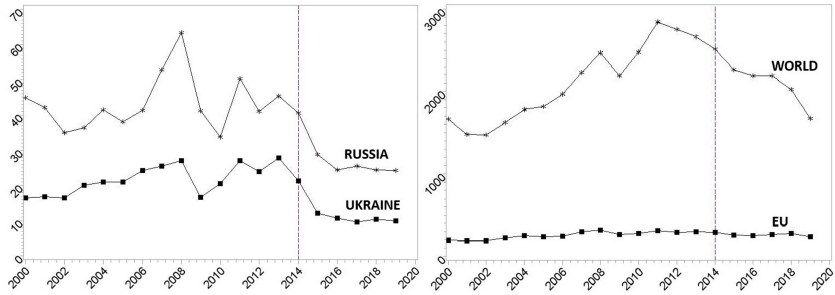

Figure 1. Value of exports of agricultural products for Ukraine, Russia, the EU and the world. Notes: the author's estimates using data from the ITDP-E database combined with the World Development Indicators deflator. Units are in constant million $US.

shipments. Following the implementation of the EU Solidarity Lanes, agricultural commodity futures prices declined (Goyal and Steinbach, 2023). The Black Sea Grain Initiative further reduced prices by 7.9 per cent (Poursina *et al*., 2024). However, its effect on market uncertainty was limited, as its impact was largely anticipated by the markets (Goyal and Steinbach, 2023; Branger, Hanke and Weissensteiner, 2023).

Among the many economic consequences of the war, the disruption of agricultural trade flows stands out as particularly relevant to this study. An examination of recent trends in agricultural exports (Figure 1) reveals that, after 2014, there was a significant decline in the total value of exports for both Russia (a decrease of 43.6 per cent from 2013 to 2017) and Ukraine (−64.9 per cent). Similarly, decreases were observed in global agricultural exports (−17.7 per cent) and exports from the EU (−11.4 per cent).

Decreases in trade flows were complemented by significant reallocations of trade patterns for many products, including agricultural commodities (Dabrowski, Domínguez-Jiménez and Zachmann, 2020; Bentley *et al*., 2022; Steinbach, 2023). Ukrainian agri-food exports to Russia fell by 93 per cent, while exports to the EU rose by 104 per cent. Imports from Russia decreased by 84 per cent, while those from the EU only dropped by 24 per cent (Boyko, Nes and Schaefer, 2023).[4] Cheptea and Gaigné (2020) conclude that exports from Russia shifted to third countries.

Ukraine and Russia are key exporters of several staple agricultural commodities. In 2019, Russia accounted for 15.86 per cent of global wheat exports,

4 A similar trend is observed for the total value of exports. In 2012, Ukraine exported 25.7 per cent of its goods to Russia and 24.9 per cent to the EU. By 2018, exports to Russia had decreased to 7.7 per cent, while those to the EU rose to 42.6 per cent (Dabrowski, Domínguez-Jiménez and Zachmann, 2020). Ukraine imported 32.4 per cent of its products from Russia and 31 per cent from the EU in 2012, and by 2018, Russia's share of imports dropped to under 15 per cent, while the EU's share increased to 41 per cent.

while Ukraine made up 8.33 per cent, ranking first and fifth globally, respectively (Table 1). Both countries are among the top 10 exporters of wheat, corn, other cereals, cereal products, soybeans, oilseeds and pulses. Ukraine alone supplies half of the world's sunflower oil, it is the seventh-largest exporter of soybeans and it was forecasted to be the fourth-largest exporter of corn and fifth in wheat for the 2021/22 season (USDA, 2022). Despite declines in export values (Figure 1), both nations advanced in global export rankings from 2013 to 2019 across various agricultural categories. Given their substantial global share, disruptions in these countries are likely to affect international markets, prices and supply chains.

The empirical literature has utilized the structural gravity model to assess the impact of the war on global trade. Cheptea and Gaigné (2020) analyzed the Russian food embargo focusing on EU food exports, Russian food imports and Russian imports of EU-banned products. They found that the embargo caused an 80 per cent decline in banned food exports from the EU to Russia, with losses amounting to €125 million per month. However, these losses were offset by increased sales within the EU and to third countries. Kutlina-Dimitrova (2017) supported this result, noting that the overall impact on the EU was minimal despite an uneven distribution of the effects.

Larch, Luckstead and Yotov (2024) studied the impact of sanctions on agricultural trade using a structural gravity model, incorporating data from the International Trade and Production Database for Estimation (ITDP-E) and the Global Sanctions Database (GSDB). They explored the heterogeneous impact of different types of sanctions on agricultural trade, including industry and product-specific effects, as well as a counterfactual scenario for 2014 using World Input-Output Database data. Their findings revealed a 10 per cent decrease in agricultural trade between sanctioned and sanctioning countries, with complete sanctions having a notably stronger negative effect than partial ones. The study showed that sanctions had a disproportionately larger impact on trade between Russia and the EU, where agricultural trade declined by 62 per cent, compared to a 39 per cent decline in trade between Russia and other sanctioning countries.

Crozet and Hinz (2016), using a structural gravity framework and GE counterfactual analysis, found that EU exports to Russia declined by 27.5 per cent after 2014, while non-EU countries saw a 35.1 per cent drop. They argued that the decrease in trade was primarily due to increased country risk rather than a change in Russian consumer preferences. This view was supported by Fritz et al. (2017), who attributed the trade decline not only to sanctions but also to other factors, such as the Russian economic downturn, driven by falling oil prices and the ruble's depreciation. Garashchuk, Isla Castillo and Podadera Rivera (2022) also noted that the ruble devaluation had a positive effect, while both geographical distance and sanctions had negative impacts on trade between the EU and Russia.

The existing literature has explored various aspects of the Russo-Ukrainian war's impact on global economies, with studies such as Larch, Luckstead and Yotov (2024) and Cheptea and Gaigné (2020) being particularly relevant to this

Table 1. Percentage of each sector in agriculture in world export (values) for 2013 and 2019 for Russia and Ukraine and global markets rankings by sector

		Russia				Ukraine			
		2013		2019		2013		2019	
ID	Industry	Percentage	Rank	Percentage	Rank	Percentage	Rank	Percentage	Rank
1	**Wheat**	**6.82%**	**5**	**15.86%**	**1**	**4.18%**	**8**	**8.33%**	**5**
2	Rice (raw)	0.45%	19	0.43%	20	0.08%	38	0.01%	65
3	**Corn**	**1.58%**	**10**	**1.73%**	**8**	**10.21%**	**4**	**13.55%**	**4**
4	**Other cereals**	**4.91%**	**8**	**8.41%**	**5**	**5.34%**	**7**	**5.81%**	**7**
5	**Cereal products**	**4.57%**	**7**	**9.25%**	**2**	**6.66%**	**3**	**7.68%**	**3**
6	**Soybeans**	0.06%	18	**0.53%**	**9**	**1.26%**	**8**	**1.88%**	**6**
7	**Other oilseeds**	1.41%	17	2.83%	12	**5.23%**	**4**	**5.71%**	**2**
8	Animal feed ingredients	1.34%	17	1.84%	13	0.33%	35	0.57%	30
9	Raw and refined Sugars and Sugar Crops	0.02%	34	0.01%	36	0.00%	74	0.00%	59
10	**Other sweeteners**	0.09%	52	0.19%	43	2.65%	12	**5.11%**	**6**
11	**Pulse and legumes**	**2.31%**	**10**	**3.72%**	**8**	0.60%	19	1.46%	13
12	Fresh fruit	0.07%	76	0.09%	68	0.02%	98	0.03%	91
13	Fresh vegetables	0.09%	63	0.29%	39	0.22%	43	0.06%	72
14	Prepared fruits and vegetable	0.10%	54	0.11%	51	0.12%	47	0.15%	49
16	Nuts	0.04%	77	0.26%	39	0.59%	28	0.57%	28
17	Live cattle	0.16%	38	0.31%	36	0.13%	41	0.73%	25
18	Live swine	0.00%	41	0.04%	33	0.00%	59	0.05%	29
19	Eggs	0.60%	26	0.92%	21	1.74%	13	1.76%	13
20	Other meats, livestock and live animals	0.25%	36	0.30%	36	0.04%	83	0.07%	70
21	Cocoa and cocoa products	0.00%	73	0.02%	53				
22	Beverages Not Elsewhere Classiffied	0.45%	30	0.43%	33	0.01%	96	0.01%	94
23	Cotton	0.01%	76	0.01%	82	0.00%	106	0.00%	137
24	Tobacco leaves and cigarettes	0.24%	38	0.31%	38	0.02%	74	0.00%	99
25	Spices	0.15%	49	0.26%	40	0.09%	67	0.05%	77
26	Other agricultural products	0.24%	52	0.39%	38	0.18%	60	0.23%	54

Notes: the author's estimates using ITDP-E data. "Percentage" indicates the percentage share of global exports in each sector that Russia and Ukraine retained in the years 2013 and 2019. The "Rank" column indicates the country's rank in global export share over all exporters. Bold values indicate sectors where the country ranks top 10 in global exports.

research. While Larch, Luckstead and Yotov (2024) move past the case-study approach of Cheptea and Gaigné (2020) by addressing the overall impact of a comprehensive set of sanctions on agricultural trade, their structural gravity model focuses on (1) a thorough estimation of the heterogeneous impact that different types of sanctions have on agricultural trade, discussing point estimates of regression coefficients, and (2) a counterfactual "no-sanctions" scenario for the year 2014, where the full GEPPML results allowed them to analyze the impact on consumers, producers, trade and income. Our study complements these results using a similar methodology; however, we restrict our focus to the impacts on aggregate trade values. Specifically, we expand the results by (1) studying the dynamic impact of sanctions on agricultural trade from 2014 to 2019, (2) differentiating the impact of the war from the impact of the sanctions on trade and (3) studying how the war and sanctions affected the global trade landscape. By addressing this gap, we contribute to the literature by providing a theoretically grounded estimation of the effects on global trade.

3. Theory

To study the impact of the annexation of Crimea and the continuing conflict between Ukraine and Russia on agricultural trade, we employ counterfactual scenarios estimated through GEPPML (Anderson, Larch and Yotov, 2018) models, which are based on the structural gravity model (Anderson and van Wincoop, 2003). The gravity model is a GE model that considers multiple countries and sectors and it can be used "to capture the possibility that markets (sectors, countries, etc.) are linked and that trade policy changes in one market will trigger ripple effects in the rest of the world" (Yotov *et al*., 2016). The GEPPML method is, therefore, appropriate in our case, as we need to examine the indirect impact that an event in Country A has on Country B.

We start with the equation presented by Anderson and van Wincoop (2003) for the estimation of the gravity model:

$$X_{ij,t} = \frac{Y_{i,t}Y_{j,t}}{Y_t^w}\left(\frac{T_{ij,t}}{P_{i,t}P_{j,t}}\right)^{1-\sigma} \tag{1}$$

In Equation (1), $X_{ij,t}$ represents exports from county i to country j at time t. The economic mass of countries i and j, represented by the value of production of country i and the value of consumption of country j, are $Y_{i,t}$ and $Y_{j,t}$ respectively, while $Y^w = \sum_i Y_i$. The intuition follows the traditional model that suggests that the value of exports is going to be larger with larger sized economies. $\left(\frac{T_{ij,t}}{P_{i,t}P_{j,t}}\right)^{1-\sigma}$ reflects the effect of costs on frictionless trade, where $T_{ij,t}$ is the bilateral trade cost factor between countries i and j. Bilateral trade costs are usually captured by time-invariant variables such as the distance, contiguity, common language, colonial history and time-varying factors such as trade policies and free trade agreements. σ is the elasticity of substitution across varieties. $P_{i,t}$ *and* $P_{j,t}$ represent the outward and inward Multilateral

Resistance Terms (MRTs), respectively, the main innovation of Anderson and van Wincoop (2003), which are the unobserved trade barriers for importers and exporters with all their trade partners.[5]

Once the theoretical foundations of the gravity model were accepted by the scientific community, the literature quickly turned toward dealing with the problems presented in the empirical estimation of the structural gravity model, dealing with heteroscedasticity that is inherent in trade data, the presence of zero trade flows and the theoretically consistent inclusion of MRTs in the specification. Santos Silva and Tenreyro (2006) and Santos Silva and Tenreyro (2011) solved the first two problems when they used the PPML estimator toward the estimation of the gravity model. The PPML is robust to many forms of heteroscedasticity, the estimation of trade flows is made in levels allowing for the inclusion of zero trade flows, it provides consistent information given the use of proper variables and the data do not have to be discrete.

Once the PPML is employed toward the estimation of the structural gravity model, we must deal with the problem of MRTs. Multilateral resistances represent GE forces so we cannot resort to traditional panels for exports of a single country to all its destinations. Instead, we need to employ trade flows from multiple exporters to multiple importers to capture the average resistance. While numerous approaches were suggested, the inclusion of exporter-time and importer-time fixed effects in the specification is nowadays standard in the literature as the fixed effects are consistent with the respective theoretical constructs, that is, the MRTs (Olivero and Yotov, 2012; Fally, 2015).

Following Equation (1), the general form for the empirical PPML specification of the structural gravity is as follows:

$$X_{ij,t} = exp\left(\beta_0 + \beta \log\left(Z_{ij,t}\right)' + \gamma\left(T_{ij,t}\right)' + \chi'_{i,t} + \pi'_{j,t}\right)\varepsilon_{ij,t} \tag{2}$$

where $X_{ij,t}$ represents the (nominal) value of exports, and the intercept $\beta_0 = Y^w$ represents the aggregate trade value. $Z_{ij,t}$ is a vector for the economic size of the countries i and j (these are Y_{it} and Y_{jt} in Equation (1)).[6] T represents a vector that includes bilateral trade costs ($T_{ij,t}$ in Equation (1)), while $\chi'_{i,t} = P_{i,t} + Y_{i,t}$ are the exporter-time fixed effects capturing the outward multilateral resistances and $\pi'_{j,t} = P_{j,t} + Y_{j,t}$ are the importer-time fixed effects capturing the inward multilateral resistances (also see Luckstead, 2024). $\varepsilon_{ij,t}$ is the error term. The multilateral resistances capture the importer's and exporter's ease of market access, which means that they account for changes that affect access to the market, such as the downturn of the Russian economy, falling oil prices and the ruble's depreciation. These factors can directly influence trade costs

5 We note that there are other theoretical foundations that can give rise to isomorphic gravity equations of trade (Arkolakis, Costinot and Rodriguez-Clare, 2012) such as Costinot and Rodriguez-Clare (2014), Eaton and Kortum (2002), Melitz (2003) and Chaney (2008).

6 These were traditionally captured by $GDP_{i,t}$ and $GDP_{j,t}$; however, this practice is not consistent with theory as they are measured in value added rather than gross values (Arkolakis, Costinot and Rodriguez-Clare, 2012). They are captured by the value of production $\left(Y_{i,t}\text{ - see equation 1}\right)$, and the value of importer's expenditures $\left(Y_{j,t}\right)$ (Head and Mayer, 2014: 138).

by altering the relative prices of goods, the competitiveness of exports and the cost of importing.

Additional problems to the empirical specification are presented when the impact of nondiscriminatory trade policy variables needs to be estimated. The inclusion of MRTs in the specification $\left(\chi'_{i,t} and \pi'_{j,t}\right)$ absorbs the effect of any variables that represent unilateral and nondiscriminatory trade policies (including $Z_{ij,t}$).[7] Following Heid, Larch and Yotov (2021) and Yotov (2022), the data include intra-national sales, allowing for $i = j$. The combination of trade data with intra-national sales, estimated as the difference between gross production values and exports (Heid, Larch and Yotov, 2021), solves this problem allowing parameter identification. This is the case, when the country-specific trade policies do not apply to intra-national trade but do apply to international flows. Heid, Larch and Yotov (2021) state that "… the use of intra-national trade allows identification of unilateral and non-discriminatory trade policies even in the presence of importer and exporter fixed effects, since the trade policies apply only to international trade flows, while the fixed effects are defined for both international as well as intra-national observations." The importance of intra-national sales is further emphasized by Yotov (2021, 2022), who summarizes 15 reasons why domestic trade flows are important for theory-consistent estimation of structural gravity. The inclusion of intra-national sales to the data extends the applicability of structural gravity models as it allows the identification of policy variables that are country specific, such as the ones we deal with in this research.

The application of the structural gravity model in our case will also require the contribution of Anderson, Larch and Yotov (2018) for the creation of counterfactual scenarios and the estimation of the impact of the Crimea annexation to third countries. We apply two counterfactual scenarios. First, we examine the counterfactual scenario of "no annexation/war, no sanctions," and second, we examine the scenario of "no sanctions." The two scenarios allow us to discuss the distribution of impacts on global exports due to the war but also the impact and effectiveness of the sanctions.

Finally, we estimate the changes in the trade potential for Russia, Ukraine and the EU after 2014. The trade potential literature examines the difference between predicted and actual values of trade (Baldwin, 1994; Nilsson, 2000; Egger, 2002) trying to capture the maximum trade between two countries given the economic characteristics of the countries and considering that there are no frictions to trade and markets are open. Technical details and limitations of our analysis are discussed in the next section, following the presentation of the models.

7 The theoretical MRT constructs are necessary in the estimation of a structural gravity model; however, they absorb the effect of $Y_{j,t}$ and $Y_{i,t}$, so we cannot conclude on the effect these determinants have on export values. While this was a popular research topic in the past, the inability to estimate the impact of $Y_{j,t}$, $Y_{i,t}$ on exports does not affect our results. We note, however, that this problem is one of the reasons for some confusion in the literature, where attempts to estimate the impact of the main determinants of export values run to a sudden halt when the theory is properly applied.

4. Methodology and data

Our estimates follow the techniques presented in the work of Yotov et al. (2016) to ensure a theoretically consistent estimation of the gravity model. We start our estimation for the impact of the Crimea annexation on agricultural trade with a baseline PPML model for export flows, derived from Equation (2):

$$X_{ij,t} = exp\left(\gamma_1 FTA_{ij,t} + \gamma_2 WTO_{ij,t} + \gamma_3 EU_{ij,t} + \gamma_4 Sanctions_{ij,t} + \sum_{k=2014}^{2019} \delta_k Rus_{i,t}^k + \sum_{k=2014}^{2019} \theta_k Ukr_{i,t}^k + \sum_{k=2014}^{2019} \left(\lambda_k Rus_{i,t}^k \cdot sanctions_{ij,t}^k\right) + \sum_{k=2014}^{2019} \left(\varphi_k Ukr_{i,t}^k \cdot sanctions_{ij,t}^k\right) + \chi'_{i,t} + \pi'_{j,t} + \mu'_{ij}\right) \varepsilon_{ij,t} \quad (3)$$

In Equation (3), the variables $Rus_{i,t}^k$ and $Ukr_{i,t}^k$ represent indicator variables that take the value of 1 for export flows from Russia and Ukraine for the respective years ($k = 2014 - 2019$) and 0 for all other observations. We consider that during the years following the annexation of Crimea, there were "man-made/artificial" trade costs (see Bergstrand and Egger, 2013) present that impeded trade. These costs are captured by the dummy variables included in our specification. Our definition of these variables therefore represents increased costs due to the annexation. These take the value of 1 only for international flows but not for intra-country sales, allowing for the estimation of a coefficient in light of the multilateral resistances fixed effects that are included $(\chi'_{i,t}, \pi'_{i,t})$. The variable $\text{Sanctions}_{ij,t}$ is an indicator variable that takes the value of 1 for country pairs (i,j), where sanctions were imposed at time t by the importing country. Post-annexation variables are interacted with the sanctions/punitive trade measures imposed by specific countries after 2014 for Russia $\left(\sum_{k=2014}^{2019} \left(\lambda_k \text{Rus}_{i,t}^k \cdot \text{Sanctions}_{ij,t}^k\right)\right)$ and for Ukraine $\left(\sum_{k=2014}^{2019} \left(\varphi_k \text{Ukr}_{i,t}^k \cdot \text{Sanctions}_{ij,t}^k\right)\right)$ so that we can separate their impact from the effect of the war.

Our model also includes country-pair fixed effects (μ_{ij}), that absorb the effect from variables that vary bilaterally, included in the $T_{ij,t}$ vector, such as common language, borders, distance and historical colonial relationships. The fixed effects are included in the specification to mitigate endogeneity of the FTA variable with trade costs (Baier and Bergstrand, 2007). Country pairs, members of a free trade agreement decrease restrictions, have lower costs of trade and end up with higher levels of trade. However, two countries that already share a high level of trade, possibly due to similarity of preferences, closeness, etc., are more likely to sign an agreement to liberalize trade, therefore resulting in reverse causality in the gravity model. To confront this problem, initially recognized by Trefler (1993), and to deal with the endogeneity of trade policy variables, Baier and Bergstrand (2007) propose the use of average treatment methods through first-differencing or country-pair fixed

effects. The country-pair fixed effects account for all time-invariant trade costs and the endogeneity of the FTA variable.[8] Although the fixed effects absorb the effect of variables that vary bilaterally, Egger and Nigai (2015) and Agnosteva, Anderson and Yotov (2014, 2019) support that the country-pair fixed effects capture bilateral trade costs better than variables traditionally employed in the gravity equation.

The separability property of the structural gravity model allows us to estimate Equation (3) at any level of aggregation (Anderson and van Wincoop, 2004). Therefore, we first estimate our aggregate model, which includes all sectors, and then we estimate sectoral models for the most important sectors in Russia's and Ukraine's agriculture to gain additional insight into the effects of the conflict. Standard errors in the estimation are clustered by country-pair at industry level, and by country-pair-industry at a disaggregated level (Egger and Tarlea, 2015).

Once we estimate our baseline model, we continue with GEPPML (Anderson, Larch and Yotov, 2018) to project the impact of the annexation on affected countries by creating a counterfactual scenario of "no-annexation/war and no sanctions" and a scenario of "no-sanctions" only[9] using the two-step procedure by Anderson and Yotov (2016) to recover missing trade costs. In our first scenario (no-annexation/war and no sanctions), our baseline is the scenario without war and without sanctions, whereas the counterfactual assumes that the war occurred and the sanctions were imposed. In our second scenario (no sanctions), our baseline is the scenario without sanctions but with the war, whereas the counterfactual assumes that the war occurred and the sanctions were imposed. To understand the mechanics of the counterfactual that allow us to get the conditional GE impacts on trade, we elaborate on the first scenario. We first employ the estimates of Equation (3) and we retrieve the predicted coefficients. These are used to obtain estimates of the bilateral, country-pair fixed effects for those country-pairs with non-zero trade flows $\left(\hat{\mu}_{ij}\right)$. We also retain the coefficients of the dummy variables and the interaction variables for Russia and Ukraine from this original model for the next steps.

In the second step, we need to fill in missing trade cost values and construct the full matrix of bilateral trade cost. We employ the estimates of the country-pair fixed effects $\left(\hat{\mu}_{ij}\right)$ from Equation (2) as the dependent variable, where the independent variables are the fixed effects and the standard gravity variables:

$$t_{ij}^{1-\sigma} = \exp\left(\hat{\mu}_{ij}\right) = \exp\left(\pi_i + \chi_i + \upsilon_1 \ln\left(\text{Distance}_{ij}\right) + \upsilon_2 \text{Contiguity}_{ij} + \upsilon_3 \text{Colony}_{ij} + \upsilon_4 \text{Language}_{ij}\right)\varepsilon_{ij} \quad (4)$$

8 Baier and Bergstrand (2007) further highlight that country-pair fixed effects resolve endogeneity from omitted variables, but not reverse causality.

9 The GEPPML counterfactuals employ a subset of 50 countries to allow PPML estimation without dropping additional fixed effects, which is possible when trade flow data are missing or zero (Yotov *et al.*, 2016: 96). Our chosen set of countries covers 69 per cent of total agricultural exports (2019) and allows the estimation of all our counterfactual scenarios for all years with the same set of countries.

We use the predictions from Equation (4) to fill in missing trade cost values and construct the complete set of bilateral trade costs (also see Anderson and Yotov, 2016). So, we add the impact of the Russo-Ukrainian war and the remaining exogenous variables estimated from the previous step (Equation (3)) to compute the fitted bilateral trade costs under our baseline scenario of no war and no sanctions:

$$\begin{aligned}\left(\hat{t}_{ij}^{BLN}\right)^{1-\sigma} &= exp\Big(\hat{\mu}_{ij} + \hat{\gamma}_1 FTA_{ij} + \hat{\gamma}_2 WTO_{ij} + \hat{\gamma}_3 EU_{ij} + \hat{\gamma}_4 \cdot \widetilde{Sanctions}_{ijt} \\ &+ \sum_{k=2014}^{2018} \hat{\delta}_k \widetilde{Rus}_i^k + \sum_{\xi=2014}^{2018} \hat{\delta}_\xi \widetilde{Ukr}_i^\xi \\ &+ \sum_{k=2014}^{2019} \left(\hat{\lambda}_k \widetilde{Rus}_i^k \cdot \widetilde{Sanctions}_i^k\right) \\ &+ \sum_{\xi=2014}^{2019} \left(\hat{\varphi}_k \widetilde{Ukr}_i^\xi \cdot \widetilde{Sanctions}_i^\xi\right)\Big)\end{aligned} \tag{5}$$

In Equation (5), the variables related to the war are set to 0 $\left(\widetilde{Rus}_i^k, \widetilde{Ukr}_i^\xi\right)$ and the sanctions are set to 0 for sanctions against Russia and Ukraine $\left(\widetilde{Sanctions}_{ijt}\right)$. The full vector of bilateral trade costs is used as a constraint in a baseline gravity specification. We can therefore estimate trade and obtain predicted values $\left(\hat{X}_{ij}^{BLN}\right)$ using only exporter-time and importer-time fixed effects, constraining our model with the complete set of bilateral, baseline and trade costs ("offset" command in Stata "ppml" command):

$$X_{ij}^{BLN} = exp\left(\chi_{i,t}' + \pi_{j,t}' + \overline{\hat{t}_{ij}^{BLN}}\right)\varepsilon_{ij,t} \tag{6}$$

Next, we compute the fitted bilateral trade costs under our counterfactual scenario, where the war occurred and the sanctions were imposed, allowing the dummy variables and the interaction variables to take their actual values:

$$\begin{aligned}&\left(\hat{t}_{ij}^{CFL}\right)^{1-\sigma} = exp\left(\hat{\mu}_{ij}^{CFL}\right) \\ &= exp\Big(\hat{\mu}_{ij} + \hat{\gamma}_1 FTA_{ij} + \hat{\gamma}_2 WTO_{ij} + \hat{\gamma}_3 EU_{ij} + \hat{\gamma}_4 \cdot Sanctions_{ijt} \\ &+ \sum_{k=2014}^{2018} \hat{\delta}_k Rus_i^k \\ &+ \sum_{\xi=2014}^{2018} \hat{\delta}_\xi Ukr_i^\xi + \sum_{k=2014}^{2019} \left(\hat{\lambda}_k Rus_i^k \cdot Sanctions_i^k\right) \\ &+ \sum_{\xi=2014}^{2019} \left(\hat{\varphi}_k Ukr_i^\xi \cdot Sanctions_i^\xi\right)\Big)\end{aligned} \tag{7}$$

where CFL stands for counterfactual. Again, we estimate trade and obtain predicted values $\left(X_{ij}^{CFL}\right)$ using only exporter-time and importer-time fixed effects, constraining our model with the counterfactual values to ensure that the only parts of trade costs that change are the dummy variables for the

Russo-Ukrainian war:

$$X_{ij}^{CFL} = \exp\left(\chi'_{i,t} + \pi'_{j,t} + \overline{\hat{t}_{ij}^{CFL}}\right)\varepsilon_{ij,t} \tag{8}$$

Finally, we use the predicted trade estimates from the baseline $\left(\hat{X}_{ij}^{\mathrm{BLN}}\right)$and the counterfactual scenario $\left(\hat{X}_{ij}^{\mathrm{CFL}}\right)$ to retrieve the percentage change with respect to the baseline scenario, which reflects the conditional GE estimate of the impact on trade. The conditional GE indexes allow for changes in both trade costs and the inward and outward multilateral resistances, but we treat as constant any changes in output and expenditures.

In the last step, we employ the coefficients of the first stage baseline model (3) to estimate the trade potential for Russia and Ukraine and we extend our results to the EU, with each one of the trading partners (Baldwin, 1994; Nilsson, 2000; Egger, 2002). The trade potential is estimated by obtaining centered predicted estimates and comparing them with actual values for the years after 2013. Using, for example, the year 2014, the trade potential is equal to $TP_{i,j,2014} = \frac{\hat{X}_{i,2014}}{X_{i,2014},}$. The ratio of predicted to actual bilateral trade allows us to explore if export potential toward specific destinations around the world has been exhausted, given the specific economic characteristics of each trading partner. When this trade potential value is more than 1, our model predicts a higher level of trade as compared to the value observed so that exports toward destinations can be increased. When the value is less than 1, trade potential has been exhausted and other characteristics of partner countries would need to change to allow for further increases in trade flows.

To estimate the potential for the EU, we treat the EU as one single country (Dadakas, Ghazvini Kor and Fargher, 2020; Dadakas, 2021), where the weighted trade potential toward destination j is estimated as follows[10]:

$$TP_{EU,j,2014} = \sum_{i=1}^{28}\left(\frac{\hat{X}_{ij,2014}}{X_{ij,2014}}\frac{X_{ij,2014}}{\sum_{i=1}^{28}X_{ij,2014}}\right) \tag{9}$$

where $i = EU28\ countries$.

There are two important limitations to our analysis. The first limitation relates to the definition of the dummy variables within the method proposed by Heid, Larch and Yotov (2021). The dummy variables, for every year after the

10 We demonstrate a four-country average using the Visegrad 4 (Slovakia, Czechia, Poland and Hungary) countries. Let the trade potential of Visegrad members with e.g. Germany be equal to 1 for three out of four countries, but equal to 5 for Poland. We want to estimate the average trade potential weighing by the level of exports. Let exports to Germany equal to 2 for three out of four Visegrad members and equal to 14 for Poland, so that total Visegrad exports to Germany are equal to 20. Therefore, the weight for three countries is 0.1 (=2/20) each, and 0.7 (=14/20) for Poland. The average trade potential of the V4 to Germany, weighted by the size of the exports of each country, is equal to $TP_{Visegrad,Germany,2016} = 1 \cdot 0.1 + 1 \cdot 0.1 + 1 \cdot 0.1 + 1 \cdot 0.1 + 5 \cdot 0.7 = 3.8$. Our measure places more weight on countries with high levels of exports toward each destination. The same measure is employed for all destinations of EU countries to get an estimate of the trade-weighted, trade potential for each destination.

annexation, take the value of 1 only for inter-country sales, but not for intra-country sales. This implies that the impact of the war is limited to international trade and does not extend to domestic sales. This is necessary, however, to obtain parameter estimates from PPML that are not absorbed by the MRTs. The second limitation is related to the definition of the counterfactual in our analysis and the estimation of the conditional GE effects. The estimation of the effects assumes that the total output and expenditures remain constant in the two scenarios. However, these were not fixed during the annexation as both loss of land and loss of productive factors affected output and expenditures.

We employed the GSDB (Felbermayr *et al*., 2020; Kirilakha *et al*., 2021; Syropoulos *et al*., 2023) that includes bilateral information on sanctions imposed since the 1950s, amending information where necessary to properly account for the sanctions against Russia and Ukraine in our specification. We also used the ITDP-E (Borchert *et al*., 2021, 2022) for the estimation of the gravity model because it offers consistently constructed intra-country sales, so that our results can be comparable to the results of previous studies (Larch, Luckstead and Yotov, 2024). The ITDP-E database, version 2.1, covers 265 countries and 170 industries, and it provides disaggregated data with a total of 72.5 million observations. Of these observations, 6.85 million correspond to agricultural product categories 1 through 26. The original data for agriculture come from the Food and Agriculture Organization of the United Nations Statistics Division. We do not include the forestry and fishing sectors (categories 27 and 28 in agriculture) as the data originate from a different source. We use data from 1990 to 2019. Of the trade data, 65.8 per cent are zeros at the disaggregate sector level. At the aggregate level, we have 864,635 bilateral yearly observations, of which 50.1 per cent are zeroes stressing the necessity of a method that allows for the inclusion of zero values in the dependent variable during estimations. Of these usable observations, 4,237 reflect intra-country sales. We employ both aggregate, annual country-level data and sectoral data for agricultural products, and we use consecutive-year data (Egger, Larch and Yotov, 2022).

Exports are included in nominal terms (US dollars) because, in structural gravity models, these are deflated by the MRTs included in the specification of the model (De Benedictis and Taglioni, 2011; Shepherd, 2013). Table 2 provides descriptive statistics for the main variables included in the study.

5. Results

5.1. Gravity model estimation

The first part of our results comprises the baseline PPML regression estimates, presented through models (1) and (2) of Table 3. We utilize aggregate data, dummy variables for the post-annexation years for both Russia and Ukraine, as well as variables for the sanctions, which enable us to distinguish the effect of the war, i.e. the post-annexation period, from the impact sanctions had on

Table 2. Descriptive statistics

Variable	Mean	SD Over Overall	SD Between	SD Within	Min	Max	Obs.	Groups
Exports	14.07	174.1	136.75	100.3	0	29,566.09	719,899	26,830
EU	0.02	0.14	0.11	0.07	0	1	719,899	26,830
RTA	0.21	0.41	0.35	0.2	0	1	719,899	26,830
WTO	0.57	0.5	0.37	0.35	0	1	719,899	26,830
Distance	7354.78	4412.36	4427.14	2.08	66.83	19,746.33	716,305	26,450
Colony	0.02	0.13	0.13	0	0	1	719,899	26,830
Contiguity	0.02	0.15	0.15	0.01	0	1	719,899	26,830
Language	0.36	0.48	0.48	0	0	1	719,899	26,830

Notes: the author's estimates, and exports units are millions of current US dollars. EU, RTA, WTO, Colony, Contiguity and Language are dummy variables, and distance is measured in kilometers.

Table 3. PPML regression results

	Agriculture											
Model number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Depended	Exports of agriculture in		Sec. 1	Sec. 3	Sec. 4	Sec. 5	Sec. 6	Sec. 7	Sec. 10	Sec. 11	Sec. 13	Sec. 19
	Aggregate		Wheat	Corn	Other cereal	Cereal	Soybeans	Other oilseeds	Other sweet	Pulse	Fresh	Eggs
RTA	**0.25*****	**0.25*****	0.12	**0.34****	−0.25	0.13	0.05	**0.24***	0.13	**0.44*****	**0.62*****	**0.34****
	(0.04)	(0.04)	(0.09)	(−0.13)	(−0.2)	(−0.2)	(−0.1)	(−0.13)	(−0.1)	(−0.06)	(−0.12)	(−0.13)
EU	**1.03*****	**1.03*****	**1.76*****	**1.67*****	**3.35*****	**1.52*****	**0.98*****	**1.20*****	**0.54****	**1.42*****	**2.96*****	**1.67*****
	(0.12)	(0.12)	(0.25)	(−0.23)	(−0.5)	(−0.43)	(−0.22)	(−0.29)	(−0.27)	(−0.2)	(−0.37)	(−0.23)
WTO	**0.71*****	**0.71*****	0.11	−0.25	0.31	**1.90*****	**0.64*****	0.03	**0.63****	−0.13	**0.47****	−0.25
	(0.10)	(0.10)	(0.20)	(−0.16)	(−0.42)	(−0.44)	(−0.19)	(−0.19)	(−0.24)	(−0.22)	(−0.23)	(−0.16)
RUSSIA 14	**0.90*****	**0.93*****	**1.26*****	0.54		0.35	**0.97*****	**2.09*****	**1.54*****	0	**1.68*****	0.54
	(0.15)	(0.16)	(0.24)	(−0.52)		(−0.34)	(−0.29)	(−0.72)	(−0.47)	(−0.68)	(−0.64)	(−0.52)
RUSSIA 15	**0.84*****	**0.87*****	**1.40*****	−0.04		**2.60*****	−0.04	**2.12*****	**1.87*****	0.58	1.82**	−0.04
	(0.15)	(0.15)	(0.25)	(−0.54)		(−0.32)	(−0.18)	(−0.78)	(−0.5)	(−0.86)	(−0.75)	(−0.54)
RUSSIA 16	**0.97*****	**0.99*****	**1.49*****	0.08		**2.29*****	**0.88*****	**2.18*****	**1.99*****	**2.16****	**1.96****	0.08
	(0.15)	(0.15)	(0.31)	(−0.49)		(−0.29)	(−0.22)	(−0.8)	(−0.44)	(−0.96)	(−0.9)	(−0.49)
RUSSIA 17	**1.25*****	**1.32*****	**0.76****	0.6		**2.02*****	**1.83*****	**1.72***	**1.98*****	**1.59****	**3.30*****	0.6
	(0.17)	(0.17)	(0.34)	(−0.45)		(−0.46)	(−0.26)	(−0.97)	(−0.46)	(−0.81)	(−0.74)	(−0.45)
RUSSIA 18	**1.68*****	**1.75*****	**2.71*****	0.71		**2.77*****	**1.48*****	**1.55***	**2.72*****	**2.30*****	**4.88*****	0.71
	(0.19)	(0.19)	(0.22)	(−1.02)		(−0.34)	(−0.57)	(−0.85)	(−0.54)	(−0.85)	(−0.88)	(−1.02)
RUSSIA 19	**1.28*****	**1.33*****	**1.17*****	−0.12		**2.71*****	**2.16*****	**1.63****	**1.96*****	**3.49*****	**4.58*****	−0.12
	(0.24)	(0.26)	(0.26)	(−0.51)		(−0.42)	(−0.38)	(−0.82)	(−0.6)	(−0.85)	(−1.09)	(−0.51)
RUS × SAN 14		−0.11	**−0.84****	**0.80***	**−3.54*****	0.46	**−0.98*****	**−2.68*****	−0.28	1.12	**−4.64*****	**0.80***

(continued)

Table 3. (Continued)

	Agriculture											
Model number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Depended	Exports of agriculture in		Sec. 1	Sec. 3	Sec. 4	Sec. 5	Sec. 6	Sec. 7	Sec. 10	Sec. 11	Sec. 13	Sec. 19
	Aggregate		Wheat	Corn	Other cereal	Cereal	Soybeans	Other oilseeds	Other sweet	Pulse	Fresh	Eggs
		(0.19)	(0.36)	(−0.41)	(−0.78)	(−0.81)	(−0.29)	(−0.63)	(−0.29)	(−0.83)	(−1.42)	(−0.41)
RUS × SAN 15		−0.09	−0.54	0.37	−0.29	−0.48	−0.31	**−3.07*****	**−1.12*****	**2.10****	**2.77*****	0.37
		(0.17)	(0.39)	(−0.37)	(−1.03)	(−0.99)	(−0.31)	(−0.74)	(−0.37)	(−0.94)	(−0.85)	(−0.37)
RUS × SAN 16		−0.07	**−0.70***	**0.93****	0.9	0.29	**−1.13*****	**−2.93*****	**−1.25*****	0.68	1.57	**0.93****
		(0.18)	(0.36)	(−0.43)	(−1.11)	(−0.81)	(−0.35)	(−0.57)	(−0.41)	(−1.09)	(−1)	(−0.43)
RUS × SAN 17		**−0.41** **	**−1.13****	0.48	0.12	**−1.39***	**−1.94*****	**−3.21*****	**−0.91****	0.93	**2.42*****	0.48
		(0.19)	(0.44)	(−0.33)	(−0.67)	(−0.75)	(−0.44)	(−0.63)	(−0.37)	(−0.93)	(−0.83)	(−0.33)
RUS × SAN 18		**−0.37***	**−0.99****	0.29	**−2.70*****	−1.37	**−1.66****	**−2.72*****	−0.09	0.12	1.03	0.29
		(0.20)	(0.47)	(−0.42)	(−0.69)	(−0.88)	(−0.68)	(−0.68)	(−0.46)	(−0.94)	(−1.08)	(−0.42)
RUS × SAN 19		−0.17	**−0.88***	0.09	**−2.00*****	0.13	**−2.02*****	**−2.65*****	**−0.93***	−1.05	1.55	0.09
		(0.23)	(0.46)	(−0.51)	(−0.7)	(−1)	(−0.55)	(−0.69)	(−0.49)	(−0.92)	(−1.21)	(−0.51)
UKRAINE 14	**1.06*****	**1.07*****	0.03	**1.06****		−0.11	0.1	**5.53*****	**1.37*****	**1.44*****	**1.72*****	**1.06****
	(0.12)	(0.11)	(0.67)	(−0.44)		(−0.95)	(−0.23)	(−1.02)	(−0.36)	(−0.33)	(−0.3)	(−0.44)
UKRAINE 15	**0.87*****	**0.90*****	**−1.70****	0.24		0.67	**−0.73*****		−0.23	**1.02*****	**2.16*****	0.24
	(0.16)	(0.16)	(0.66)	(−0.49)		(−1.05)	(−0.22)		(−0.39)	(−0.33)	(−0.45)	(−0.49)
UKRAINE 16	**0.72*****	**0.75*****	**1.11****	0.14		0.75	**−0.75*****		0.67	**1.45*****	0.42	0.14
	(0.19)	(0.19)	(0.53)	(−0.58)		(−1.02)	(−0.27)		(−0.44)	(−0.52)	(−0.65)	(−0.58)
UKRAINE 17	**0.98*****	**1.02*****		0.68		1.11	0.07		**2.09*****	**1.09****	1.14	0.68
	(0.19)	(0.18)		(−0.49)		(−0.85)	(−0.29)		(−0.49)	(−0.47)	(−0.78)	(−0.49)
UKRAINE 18	**0.78*****	**0.83*****	−0.57	−0.34		−0.49	0.04	**5.30*****		**1.67*****	1.05	−0.34
	(0.20)	(0.19)	(0.59)	(−0.53)		(−0.86)	(−0.31)	(−0.94)		(−0.49)	(−0.81)	(−0.53)
UKRAINE 19	**1.01*****	**1.05*****	0.46	0.39		**1.96****	0.53	**6.14*****		**1.92*****	**1.65****	0.39
	(0.20)	(0.20)	(0.72)	(−0.54)		(−0.96)	(−0.33)	(−0.88)		(−0.5)	(−0.83)	(−0.54)
UKR × SAN 14		**−0.67*****	−0.61	**−3.90*****		−0.14	0.19	**−4.95*****	**−3.72*****	−0.37	**−2.57*****	**−3.90*****
		(0.10)	(0.64)	(−0.48)		(−0.38)	(−0.24)	(−0.61)	(−0.48)	(−0.36)	(−0.26)	(−0.48)

(continued)

Table 3. (Continued)

	Agriculture											
Model number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Depended	Exports of agriculture in		Sec. 1	Sec. 3	Sec. 4	Sec. 5	Sec. 6	Sec. 7	Sec. 10	Sec. 11	Sec. 13	Sec. 19
	Aggregate		Wheat	Corn	Other cereal	Cereal	Soybeans	Other oilseeds	Other sweet	Pulse	Fresh	Eggs
UKR × SAN 15		**−1.62*****	**3.76*****	**2.05*****	**1.93*****		**1.73*****		−1.16	**−9.76*****	**−2.10*****	**2.05*****
		(0.30)	(0.99)	(−0.58)	(−0.68)		(−0.26)		(−1.51)	(−0.78)	(−0.31)	(−0.58)
UKR × SAN 16		**−1.80*****	**2.87*****	0.4	1.63		**1.52*****	**−5.76*****	**−4.26*****	**−9.72*****	**−8.85*****	0.4
		(0.19)	(0.57)	(−0.48)	(−1.22)		(−0.28)	(−1.61)	(−1.45)	(−1.18)	(−0.82)	(−0.48)
UKR × SAN 17		**−1.82*****	**4.82*****	**1.10****	**2.79*****		**0.70****		**−3.86*****	**−7.42*****	**−9.32*****	**1.10****
		(0.18)	(0.77)	(−0.44)	(−1.04)		(−0.31)		(−1.45)	(−1.35)	(−0.94)	(−0.44)
UKR × SAN 18		**−2.36*****	**4.81*****	1.07	2.56***		**−1.24*****		**−3.53*****	**−8.97*****	**−9.47*****	1.07
		(0.20)	(0.66)	(−0.89)	(−0.69)		(−0.34)		(−0.69)	(−0.92)	(−1.21)	(−0.89)
UKR × SAN 19		**−3.00*****		**−3.81*****	**4.14*****		**−1.27*****		**−1.63*****	**−7.94*****		**−3.81*****
		(0.19)		(−1.26)	(−1.03)		(−0.3)		(−0.51)	(−0.42)		(−1.26)
Sanctions	**−0.24*****	**−0.23*****	−0.02	−0.23	**−0.61****	**−0.52****	0.12	**−0.43***	0.14	**−0.28****	−0.14	−0.23
	(0.05)	(0.05)	(0.16)	(−0.16)	(−0.28)	(−0.24)	(−0.09)	(−0.22)	(−0.11)	(−0.12)	(−0.14)	(−0.16)
Constant	**9.52*****	**9.52*****	**7.34*****	**6.38*****	**0.86****	**6.93*****	**7.85*****	**4.01*****	**5.79*****	**9.61*****	**7.79*****	**6.38*****
	(0.09)	(0.09)	(0.16)	(−0.13)	(−0.41)	(−0.35)	(−0.16)	(−0.16)	(−0.2)	(−0.19)	(−0.19)	(−0.13)
R^2	0.995	0.995	0.983	0.993	0.984	0.826	0.990	0.992	0.955	0.979	0.998	0.997
Observations	718,798	718,798	148,646	161,416	75,904	105,875	310,796	160,048	259,152	337,524	134,605	161,416

Notes: the author's estimates. Robust standard errors are in parentheses.
$^{***}P < .01$.
$^{**}P < .05$.
$^{*}P < .1$.
Interpretation of dummy variable coefficients is done through $e^{a_i} - 1$, which are not reported on the table. All regressions include exporter-time, importer-time and country-pair fixed effects. Values in Bold indicate statistical significance.

agricultural trade flows. Models (3) through (12) present the sectoral regressions. All models include exporter-time, importer-time and country-pair fixed effects.

Starting with the coefficients on free trade agreements, EU membership and WTO membership, we find that all three coefficients, in both models, are statistically significant and carry the expected signs. The FTA coefficient suggests a 28.4 per cent $\left(=e^{0.25}-1\right)$ increase in the value of trade due to trade agreements. Our estimate falls within 1 SD of the mean value reported in structural gravity models (0.36 ± 0.42) by Head and Mayer (2014) in their meta-analysis of structural gravity results. The WTO variable shows that agricultural trade flows for WTO members are 103 per cent higher compared to nonmembers, with Larch, Luckstead and Yotov (2024) finding agricultural trade flows being 44.5 per cent higher between WTO members. Finally, EU countries exhibit 180 per cent more trade among members. Head and Mayer (2014) report a mean value of 0.16 (± 0.05), which differs substantially from our estimate for agricultural trade.

The post-annexation dummy variables in model (1) suggest positive and statistically significant impact on trade flows during the years of the war for both Russia and Ukraine. The coefficient for Russian exports in 2014 is 0.9, indicating that exports were 145.9% $\left(=e^{0.9}-1\right)$ higher than the remaining years of the study. The average, significant, post-2014, coefficient for Russia is equal to 1.15 (average 231.1 per cent increase) and for Ukraine 0.90 (average 148.6 per cent increase). These counterintuitive results suggest that, all else being equal, agricultural exports for both Russia and Ukraine increased during the years following the annexation of Crimea.

When we include the interaction variables for the sanctions imposed against (and by) Russia (model (2)), thereby distinguishing the effects of the post-annexation period from those of the sanctions, two key patterns emerge. The first relates to the impact on Russia, which was not only positive but also grew in magnitude until 2018. Russia's production and exports effectively adapted and even benefited during the war. This could be partly attributed to the ruble's devaluation and to trade reallocation (Boyko, Nes and Schaefer, 2023; Devadoss and Ridley, 2024). The second observation concerns the negative impact of sanctions on agricultural exports for both countries. The average significant effect of sanctions on Russia (2017 and 2018) was −32.3 per cent, while for Ukraine (2014 through 2019) it was −80.3 per cent. Ukraine's agricultural exports were more severely affected by the sanctions and punitive measures imposed than Russia's. Results are consistent with Larch, Luckstead and Yotov (2024: 4), who find that complete sanctions reduce trade by about 67 per cent, sanctions among Russia, the USA, the EU and allied countries decreased Russia's international trade of agricultural products by about 59 per cent and Russian sanctions on EU resulted in a decline of 62 per cent on agricultural trade.

The combined annual effect suggests that the sanctions imposed against Russia were not effective. The coefficients for the post-annexation year dummies for Russia are positive and larger, in absolute terms, than the negative

impact implied by the sanctions. For instance, for 2017, we find a positive effect of 1.32 and a negative effect of −0.41 due to sanctions, which implies a 240.7 per cent ($= (\exp(1.32) - 1) + (\exp(-0.41) - 1)$) overall increase in Russia's exports. The overall effect on Russia's trade was positive for all the years included in the study. For Ukraine, in 2015, the war shows a positive coefficient of 0.9, while the impacts from punitive measures are negative and equal to −1.62, implying a total increase equal to 65.7 per cent. The total effect for Ukraine from 2014 through 2019 was positive but lower than Russia.

When evaluating the overall effect, it is essential to explore the mechanisms driving the observed increase in trade flows. The ruble experienced a significant devaluation in January 2014 but regained some of its value by May 2015. Simultaneously, declining oil prices reduced Russia's foreign exchange earnings. EU and US sanctions on capital markets further pressured the ruble, increasing demand for foreign currency and forcing a substitution of low-cost foreign suppliers with higher-cost alternatives (Bulavin *et al.*, 2015). However, the literature also finds that while Russia's global import shares decreased after the drop in world oil prices and the ruble's depreciation, Russian consumers shifted to more affordable imported goods, opted for domestically produced alternatives, reduced their overall consumption or employed a mix of these strategies (Cheptea and Gaigné, 2020). By combining the substitution of cheaper domestically produced alternatives in consumption and production with the ruble's devaluation, we can argue that domestic products became more competitive in international markets, while trade reallocation further enabled producers to access markets unaffected by sanctions. The inflation that followed the devaluation, the embargo and increased uncertainty led the increases in food prices. The higher prices for agricultural products in international markets provided further export incentives to Russian producers.[11] The combination of cheaper domestic inputs, higher international prices, the reallocation of trade and the devaluation of the ruble can explain the, *ceteris paribus*, increase we find (in value terms) in Russia's agricultural trade flows.

Devadoss and Ridley (2024) suggest that, in the wheat markets, Russia exploited the war to its advantage to export to specific markets at the expense of Ukraine. They argue that it is not surprising that Russia benefits from the war, as it is able to sell much of its wheat in world markets at Ukraine's expense. However, the increase in exports was accompanied by the need to find alternative trade routes due to the sanctions resulting in significant reallocations of exports to many destinations (Devadoss and Ridley, 2024). The implied increase in exports and the reallocation of trade provide further support for the positive effect we find on Russia's agricultural trade flows. While our results may seem counterintuitive at first, they also offer a partial explanation for the longevity of the ongoing hostilities.

11 As a result, a wheat export tax was introduced in Russia, implemented in February 2015, to ensure adequate grain supply for the domestic population (Bulavin *et al.*, 2015). This export tax was later replaced by export restrictions, such as certificate requirements and administrative documents.

For Ukraine, the support provided by the international community, allowed staple commodities to reach countries in need. Export values increased, despite the negative impact from punitive measures imposed by Russia. However, Russia's gains exceeded those of Ukraine. Holding the negative effects from sanctions and other variables constant, during the post-annexation period, Russia's agricultural sector benefited in terms of exports, partly at the expense of Ukraine.

Our results are consistent across the sectoral regressions estimated for the most important agricultural products for Russia and Ukraine (models (3) through (12)). For all agricultural products, we find mainly a positive impact during the post-annexation years for both Russia and Ukraine, with mostly negative effects from the sanctions imposed against and by Russia. However, in the wheat market (model (3)), we find positive and statistically significant coefficients for Ukraine, suggesting that the support provided to ensure that staple commodities reached low-income countries was effective. Similar results, for some of the years in the study, are also observed for corn (model (4)) and soybean products (model (7)). These findings align with Devadoss and Ridley (2024), who argue that military conflicts should not be allowed to harm farmers in war-torn countries or lead to suffering among global consumers.

5.2. Counterfactual simulation through GEPPML

Counterfactuals are presented with the help of Table 4 and are estimated through the baseline PPML results of model (2) (Table 3). The first scenario examines the conditional GE counterfactual effects on agricultural trade in the absence of both war and sanctions. Consistent with our regression results, we find a positive impact for Russia and Ukraine during the post-annexation years.[12]

For the year 2014, Russia experienced a 54.15 per cent increase in exports due to the war and sanctions. Similar positive effects for Russia are estimated for all the years in the study, reaching a maximum of 72.57 per cent in 2018. These gains can be partially attributed to the devaluation of the ruble, as well as to a global reallocation of trade that allowed Russian exporters to adapt to international sanctions. The lowest gains for Russia appear in 2016, consistent with the export restrictions and the embargo on food products.

For Ukraine, we also observe increased exports due to the war and sanctions. In 2014, Ukraine's export gains were 15.61 per cent. While gains remained positive for all years in our study, they were substantially lower than those experienced by Russia. The decreases observed in 2015 and 2016 can be associated to reduced production and the necessary adjustment period for producers to deal with the consequences of the war within global value chains. The increases after 2016 can be linked to the signing and implementation of the FTA agreement with the EU.

12 We remind the reader that our baseline scenario is the absence of war and sanctions, and the counterfactual reflects their presence.

Table 4. GEPPML counterfactuals

	Scenario 1. No sanctions/no war						Scenario 2. No sanctions						Percentage of imp. from Russia	Percentage imp. from Ukraine
	2014	2015	2016	2017	2018	2019	2014	2015	2016	2017	2018	2019	2018	2018
RUS	54.15	29.30	25.15	51.83	72.57	46.76	−44.42	−40.06	−34.62	−37.32	−36.28	−33.50		
UKR	15.61	9.79	7.64	9.38	8.54	10.24	−6.90	−4.92	−3.54	−2.98	−21.30	−4.66		
ARG	0.02	0.01	0.00	0.01	0.01	0.00	−1.34	−0.84	−0.50	−0.80	−0.99	−0.12	0.00%	0.00%
AUS	−0.06	−0.03	−0.04	−0.06	−0.08	−0.10	−1.09	−1.72	−2.12	−1.49	−1.95	−1.89	0.01%	0.01%
AUT	0.10	−0.03	−0.03	0.03	0.19	0.07	−10.36	−10.47	−10.60	−10.93	−11.27	−10.95	0.06%	0.58%
BEL	0.19	0.10	0.08	0.15	0.23	0.20	−4.02	−3.91	−4.12	−3.94	−4.02	−3.82	0.79%	2.82%
BGR	0.08	0.05	0.03	0.05	0.07	0.02	−3.46	−3.83	−3.37	−3.93	−4.13	−3.32	0.21%	0.76%
BRA	0.07	0.04	0.05	0.07	0.04	0.00	−0.36	−0.33	−0.36	−0.28	−0.11	0.00	0.13%	0.00%
CAN	−0.01	−0.01	−0.01	−0.02	−0.03	−0.04	−2.66	−2.96	−3.24	−3.96	−4.58	−4.36	0.05%	0.01%
CHE	0.54	0.41	0.23	0.32	0.33	0.32	−12.17	−12.35	−12.37	−12.12	−12.36	−11.44	0.65%	0.22%
CHN	1.74	1.19	0.98	1.85	2.56	1.78	−4.82	−5.20	−5.00	−4.64	−4.99	−3.48	0.60%	0.97%
CYP	1.11	0.58	0.45	0.98	1.52	1.52	−11.09	−10.83	−11.23	−12.51	−14.18	−12.17	5.49%	4.22%
CZE	0.09	0.02	0.01	0.06	0.15	0.07	−8.28	−8.16	−8.28	−8.31	−9.16	−9.26	0.14%	0.51%
DEU	−0.10	−0.11	−0.13	−0.17	−0.07	−0.16	−24.77	−24.70	−24.76	−24.79	−24.76	−24.60	0.20%	1.23%
DNK	0.11	−0.05	−0.06	0.05	0.30	0.12	−6.29	−6.38	−5.85	−6.26	−6.97	−6.38	1.81%	1.81%
EGY	18.69	13.39	11.61	21.39	33.49	0.00	−15.56	−11.99	−7.15	−10.50	−19.51	0.00	21.10%	10.30%
ESP	0.68	0.47	0.38	0.57	0.72	0.80	−4.94	−4.91	−5.04	−4.89	−6.07	−4.54	1.08%	5.90%
EST	0.38	−0.01	−0.14	0.10	0.69	0.72	−9.62	−9.54	−9.97	−10.90	−12.01	−9.47	1.44%	1.89%
FIN	0.09	−0.54	−0.56	−0.08	1.15	0.27	−15.94	−15.41	−15.59	−16.80	−17.20	−16.12	0.99%	0.54%
FRA	0.04	0.02	0.01	0.01	−0.01	−0.04	−6.83	−6.90	−7.55	−7.72	−7.71	−6.97	0.06%	1.10%
GBR	−0.21	−0.16	−0.15	−0.24	−0.33	−0.57	−9.20	−9.24	−9.11	−9.21	−9.08	−8.83	0.34%	0.71%
GRC	0.97	0.55	0.43	0.91	1.32	0.90	−8.47	−9.01	−9.47	−10.23	−11.06	−8.32	4.77%	4.07%
HKG	0.00	0.00	0.00	0.00	0.01	0.00	−0.26	−0.26	−0.28	−0.27	−0.26	0.00	0.19%	0.05%
HRV	−0.13	−0.12	−0.10	−0.14	−0.12	−0.36	−12.72	−12.82	−11.68	−11.64	−11.65	−12.57	0.03%	0.30%

(continued)

Table 4. (Continued)

	Scenario 1. No sanctions/no war						Scenario 2. No sanctions						Percentage of imp. from Russia	Percentage imp. from Ukraine
	2014	2015	2016	2017	2018	2019	2014	2015	2016	2017	2018	2019	2018	2018
HUN	0.67	0.37	0.31	0.44	0.67	0.73	−6.34	−5.76	−6.58	−5.59	−7.00	−5.57	0.13%	3.86%
IDN	0.97	0.69	0.58	0.99	1.35	1.25	−6.12	−4.98	−5.11	−5.12	−6.02	−5.35	2.50%	4.91%
IRL	0.10	0.06	0.05	0.09	0.13	0.08	−6.63	−6.51	−6.96	−6.91	−7.78	−7.19	1.24%	1.58%
ITA	0.75	0.44	0.34	0.64	0.86	0.85	−10.33	−9.99	−10.22	−10.56	−11.39	−10.82	0.60%	3.16%
JPN	0.28	0.14	0.09	0.16	0.19	0.22	−4.17	−4.84	−5.03	−4.67	−7.98	−9.27	0.19%	0.25%
LTU	0.32	−0.25	−0.22	0.08	0.83	0.43	−10.19	−9.85	−7.44	−8.88	−9.35	−8.45	3.11%	2.70%
LUX	−0.02	0.00	0.01	−0.01	−0.05	−0.05	−3.39	−3.22	−3.11	−2.96	−3.34	−3.44	0.00%	0.00%
LVA	−0.03	−0.24	−0.28	−0.19	0.24	0.01	−8.72	−7.57	−7.67	−8.73	−10.24	−8.28	14.69%	1.35%
MEX	0.12	0.07	0.06	0.10	0.13	0.11	−10.24	−8.96	−8.19	−8.61	−9.06	−8.24	1.70%	0.48%
MLT	−0.88	−1.47	−1.47	−1.94	−2.13	−3.28	−13.46	−13.95	−13.37	−15.23	−15.55	−15.24	0.02%	0.24%
MYS	0.27	0.20	0.17	0.27	0.36	0.23	−8.93	−9.01	−9.22	−8.64	−9.16	−8.86	0.76%	0.61%
NLD	0.06	0.04	0.03	0.07	0.09	0.09	−0.38	−0.38	−0.40	−0.49	−0.51	−0.51	0.34%	2.63%
NOR	0.26	0.05	0.03	0.26	0.67	0.09	−11.49	−11.21	−10.98	−11.15	−11.15	−11.03	2.00%	0.64%
NZL	0.03	0.01	0.01	0.02	0.02	0.01	−2.12	−1.24	−1.13	−1.11	−1.48	−0.89	0.00%	0.01%
PAK	2.52	1.95	1.90	3.73	5.05	0.00	−6.15	−5.41	−5.43	−5.84	−7.25	0.00	1.16%	1.37%
PHL	0.86	0.67	0.54	0.94	1.37	1.56	−6.28	−5.88	−5.84	−5.94	−7.48	−7.18	3.74%	8.36%
POL	1.18	0.57	0.43	1.10	1.75	1.77	−12.41	−12.48	−14.02	−15.66	−16.73	−14.20	0.54%	2.85%
PRT	1.94	1.32	1.08	1.78	1.97	2.56	−12.86	−12.99	−13.82	−13.81	−15.47	−13.46	0.21%	5.03%
ROU	−0.08	−0.09	−0.12	−0.22	−0.29	−0.51	−6.60	−7.70	−8.77	−8.24	−8.16	−7.26	1.00%	0.87%
SAU	10.90	7.93	6.72	11.73	15.22	7.53	−6.63	−3.73	0.74	0.92	−5.91	−1.17	3.41%	3.33%
SGP	−0.02	−0.01	−0.01	−0.02	−0.02	−0.03	−2.84	−2.82	−2.74	−2.47	−2.61	−2.98	0.00%	0.05%
SVK	0.21	0.15	0.12	0.17	0.21	0.29	−9.00	−8.62	−8.85	−8.66	−8.97	−9.01	0.03%	0.17%
SVN	−0.04	−0.02	−0.02	−0.06	−0.09	−0.29	−7.15	−7.15	−7.07	−7.07	−7.38	−6.96	0.24%	0.68%
SWE	−0.08	−0.06	−0.06	−0.08	−0.01	−0.14	−11.61	−11.57	−11.68	−11.35	−11.33	−11.39	0.57%	0.08%
TUR	11.39	7.75	6.18	12.80	19.33	16.32	−11.31	−7.70	−0.89	−2.45	−7.84	−5.63	15.80%	6.41%
USA	−0.07	−0.06	−0.06	−0.10	−0.15	−0.22	−2.60	−2.67	−2.68	−2.30	−2.24	−2.15	0.04%	0.11%
ZAF	0.95	0.55	0.55	0.73	0.91	0.56	−2.04	−1.32	−1.20	−0.94	−1.13	−0.73	7.52%	0.58%

Notes: the author's estimates. The table presents conditional equilibrium percentage changes in exports as they are estimated through counterfactual scenarios estimated through GEPPML.

For the rest of the world, the impact was marginal for the most part, including countries in the EU and countries in close proximity to the war zone. Our findings agree with Cheptea and Gaigné (2020) and Kutlina-Dimitrova (2017), who report a small effect for EU members. The only countries where we observe a positive effect are those with close trade ties to Russia, such as Turkey, Saudi Arabia and Egypt, which show significant gains during the post-annexation period. These countries have a relatively high share of imports of agricultural products from Russia and Ukraine (see the last two columns of Table 4). For example, Egypt, in 2018, imported 21.1 per cent of its agricultural products from Russia and 10.3 per cent from Ukraine. This percentage grew from 7.3 per cent in 2013 to 13.5 per cent in 2014, and then to 21.1 per cent in 2018, providing additional evidence that as soon as the sanctions were imposed, Russia reallocated trade. Similar patterns of trade are observed, after 2016, with Latvia, India, South Africa, Turkey and few other countries. While close trade ties and existing relations can explain the spatial distribution of the impacts, other factors, such as distance, external policy and the ability of producers to quickly adapt to changes in global production/value chains, also influence the magnitude of transmission.

When we examine the second counterfactual, which eliminates only the sanctions but allows for the war, we find that the conditional GE estimates indicate that Russia experienced the most significant negative effects on trade flows, ranging from −44.42 per cent in 2014 to −33.5 per cent in 2019. The sanctions also had a negative effect on Ukraine. From 2014 to 2017, we observe a reduction in the severity of the sanctions' negative impact (from −6.98 per cent to −2.98 per cent). However, in 2018, our estimates indicate a sharp one-period decline of −21.3 per cent. The reduction in the negative impact observed from 2014 to 2017 for Ukraine may be attributed to the Deep and Comprehensive Free Trade Area (DCFTA) that is part of the broader Association Agreement (AA) with the EU (AA/DCFTA), which came into effect on 1 January 2016, allowing easier access for Ukraine's exports to European markets. In contrast, the significant negative effect in 2018 can be linked to Ukraine's decision to sever ties and officially withdraw from the CIS in May 2018.

Numerous other countries were also negatively affected by the sanctions, including Austria, Switzerland, Cyprus, Germany, Egypt, Great Britain, Greece, Croatia, Italy, Latvia, Mexico, Malta, Norway, Poland and Portugal. These countries import, on average, a larger percentage of their agricultural products from either Russia, Ukraine or both (see the last two columns of Table 4). The variability in the magnitude of the effects supports the findings of Boyko, Nes and Schaefer (2023), who suggest a significant reallocation of trade, and Dabrowski, Domínguez-Jiménez and Zachmann (2020), who found that the slack was picked up by substitute Eurasian countries, including Turkey.

The counterfactuals indicate that both Russia and Ukraine benefited during the war, with the majority of benefits accruing to Russia, and both were negatively affected by the sanctions. However, the conditional GE estimates also

suggest that Russia was mostly affected by the sanctions. Sanctions had a profound impact on global trade flows, affecting numerous countries worldwide. Both sanctions and counter-sanctions disrupted trade, reducing trade flows and diffusing through value chains and established trade routes that were blocked. Our results also indicate that while many countries were negatively affected by the sanctions after 2014 (scenario 2), the total impact on those countries was small (scenario 1), suggesting that swift adaptation and trade reallocations assisted those countries to quickly mitigate the effects of the war.

5.3. Trade potential estimation

Given the changes implied by the GEPPML model, we examine the trade potential (Table 5), estimated through the predicted values from our baseline PPML model (2) (Table 3). For intra-EU trade, the trade potential was near 1 since 2013, as expected in a union of countries where border restrictions have been eliminated. However, trade potential with Russia increased drastically after 2015 and remained high, reaching 1.73 in 2017. Although the EU was initially overtraded with Russia, after 2014, and given the decrease in bilateral trade caused by restrictions, the EU became undertraded. This complements the results by Cheptea and Gaigné (2020), who found that EU exports of banned products to Russia during the embargo were, on average, 80 per cent lower than in the period before the ban.

When we examine the reverse routes, specifically Russian exports to the EU, our results suggest that Russia was near the maximum trade potential after 2014, providing further support for the ineffectiveness of the sanctions. The sanctions seemed to disproportionately affect the EU rather than Russia and were not effective in this regard.

Ukraine was overtraded with the EU until 2015 and undertraded in 2016 and 2017. However, a trend reversal occurred after 2016, leading to overtrading again by 2017. These results agree with our counterfactual analysis (Table 4), which shows a decrease in Ukraine's export gains in 2015 and 2016 (15.61 per cent ➙ 9.79 per cent ➙ 7.64 per cent) and a negative impact from the sanctions during the same years (−4.92 per cent and −3.52 per cent). Similar to the previous results, we do not find a significant impact from the war and the sanctions on Ukraine's ability to export to the EU. However, we find evidence for the effectiveness of the EU–AA/DCFTA agreement. Ukraine does not show signs of significant undertrading or overtrading with Russia, with trade potential estimates remaining near 1 throughout the post-annexation period, given the sanctions that were imposed.

Both Ukraine's and Russia's trade ties were effectively disrupted, which is visible through Figure 2 where we illustrate the spatial impact and trade reallocation by plotting the bilateral trade potential estimates for the years 2013 and 2016, that is, the years before and after the annexation of Crimea.

Our results reveal a substantial shift in trade potential, indicative of swift trade adjustments and reallocations. For the EU, we find that while a trade potential was available with Asian countries and Oceania and that the EU was overtraded with Russia, by 2016 a lot of trade shifted to China (Figure 2).

Table 5. Trade potential results

Source (i) → Destination (j)	2013	2014	2015	2016	2017	2018	2019
EU → EU	1	1.01	1.02	1.02	1.01	1	1.01
EU → Russia	0.85	1	1.65	1.72	1.73	1.69	1.6
EU → Ukraine	0.51	1	1	1.35	1.31	1.31	0.91
RUS → EU	0.74	0.96	1.01	0.98	1.06	0.99	1.11
RUS → Ukraine	0.78	2.34	0.95	1.23	1.04	1.65	0.76
UKR → EU	0.64	0.88	0.98	1.4	1.18	1.04	0.84
UKR → Russia	1.29	0.99	1.2	1.05	1.03	1.07	0.98

Notes: the author's estimates. Trade potential estimates (α_{ij}) above 1 indicate that Source (i) to Destination (j) trade can be increased by a factor of α_{ij}, given the economic characteristics of the two countries.

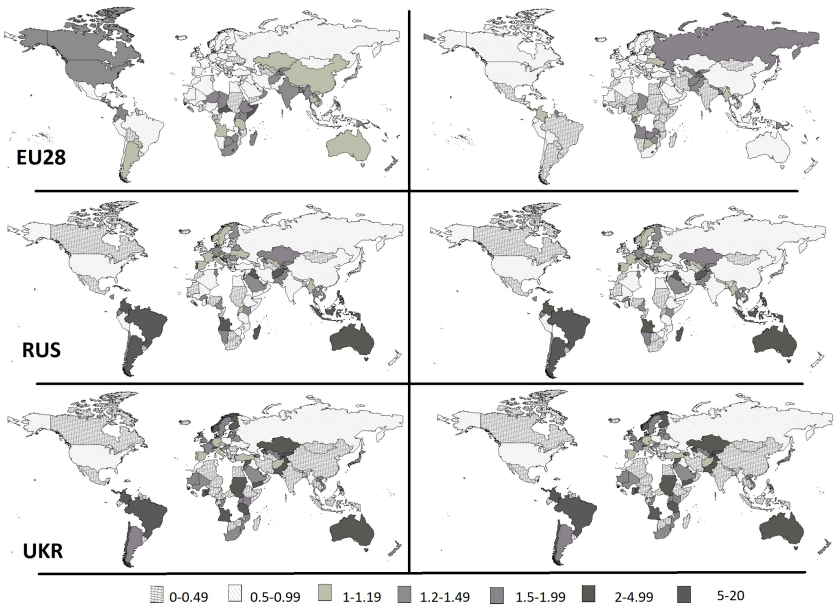

Figure 2. Trade potential results for the EU28, Russia and Ukraine for the years 2013 and 2016. Notes: the author's estimates. Solid grayscale colors indicate undertrading (TP > 1) where a potential to increase trade exists. Patterns indicate overtrading (TP < 1) where the potential to trade has been exhausted.

Trade routes changed, leading to the EU becoming overtraded with China, India, Oceania and other regions and undertraded with Russia.

This shift is also evident for Russia and Ukraine, as both show a corresponding decrease in trade potential with North America, where they are now overtraded. At the same time, they exhibit an increase in trade potential with EU countries, where they are now undertraded. Our results support Steinbach (2023), who finds that the Russia–Ukraine war resulted in considerable trade diversion, benefiting countries in North America and Europe. The literature also finds that the global "lost trade"—the difference between predicted and observed trade flows—amounts to US$3.2 billion per month (Crozet and Hinz, 2016). This cost is unevenly distributed among countries, with EU member states bearing 76.7 per cent of the overall impact. Crozet and Hinz (2016) further note that the bulk of the "lost trade" (83.1 per cent) is incurred through non-embargoed products and can hence be considered "collateral damage."

The results in Table 5, combined with Figure 2, indicate that bilateral trade relations among Russia, Ukraine and the EU have not recovered since 2014. The conflict carries dynamic effects on the trade of agricultural products. In the post-annexation period, much of the trade shifted toward China, India and North America as producers sought to adapt to the changes and restrictions imposed by the Russo-Ukrainian war.

6. Discussion

Our discussion of the results and corresponding policy considerations focuses on three principal areas: (1) the efficacy of the sanctions imposed on Russia, (2) the effectiveness of measures designed to facilitate exports from Ukraine and (3) the broader implications for conflict-affected nations, where we explore the wider consequences of the conflict, particularly for developing countries that need to secure a stable and affordable supply of agricultural commodities amidst the disruptions caused by the war.

6.1. The efficacy of the sanctions imposed on Russia

While both Russia and Ukraine were negatively affected by the sanctions, the overall effect during the post-annexation period was positive for both countries. Russia received a larger share of the benefits, with agricultural exports rising by up to 73 per cent in 2018 (GEPPML), while its trade potential with the EU was only marginally affected. Russia capitalized on new trade routes, as shown by the trade potential map, which indicates that countries such as China, India, several African nations, Japan and the USA, previously undertraded until 2013, became overtraded by 2016.

Our results support the conclusions of Devadoss and Ridley (2024), who suggest that Russia benefited from the war by selling at the expense of Ukraine, while also significantly reallocating exports to various destinations. Russia managed to retain its export levels with only a marginal impact on trade potential. It successfully shifted trade routes and, despite the negative impact of the sanctions, continued to benefit during the conflict with Ukraine. The sanctions against Russia were therefore largely ineffective; producers were well prepared with alternative routes, suppliers and buyers, and value chains were not significantly disrupted.

These results raise questions about the effectiveness of sanctions as a tool to prevent war. Sanctions are intended to pressure a targeted country into changing its behavior by restricting its access to international markets, financial systems or critical resources. However, when trade restrictions are combined with counter-sanctions, they may also harm the countries that imposed the initial sanctions (Dreger *et al.*, 2016), leading to arguments about the effectiveness of economic sanctions (Naghavi and Pignataro, 2015) and their ability to influence the behavior of the targeted country (Beladi and Oladi, 2015). The negative impact of the sanctions on third countries was evident in the GEPPML second scenario where we found numerous countries that experienced decreases in trade due to the sanctions (some exceeded 10 per cent). This observation may help explain the ongoing and escalating conflict between Russia and Ukraine. The sanctions have not effectively forced Russia to alter aggressive policies, underscoring the need for a re-evaluation of the sanctions strategy to ensure that it effectively influences the behavior of targeted nations. However, further research is needed in manufacturing, services and mining to determine if this conclusion applies to other sectors of the economy.

Future sanctions should, therefore, be more strategically targeted at critical industries and existing value/production chain infrastructures. More importantly, however, greater international cooperation should be pursued on a global level to prevent the reallocation of trade that enhances the resilience of targeted industries. By concentrating on sectors that are vital to the targeted country's economy, where sanctions can have a significant impact, policymakers can enhance the likelihood of successful sanctions strategies.

6.2. The effectiveness of measures designed to facilitate exports from Ukraine

Ukraine also experienced increases in overall trade flows during the post-2014 period, albeit smaller than Russia. The benefits peaked at 15.61 per cent in 2014 and, after a decline, rose to 10.24 per cent in 2019 (GEPPML). These increases can be attributed to the sanctions imposed on Russia, which opened certain markets to Ukrainian exports, to trade opportunities created by supportive nations and initiatives to integrate into value chains. Those include the AA/DCFTA, the latter EU solidarity lanes and the Black Sea Grain Deal. When the AA/DCFTA was signed in 2014, the EU unilaterally began reducing customs duties for products from Ukraine (Boyko, Nes and Schaefer, 2023). The effect is evident in Ukraine's GEPPML positive estimates during the war (scenario 1), the negative, but decreasing, effect of the sanctions until 2017 (scenario 2)—with the exception of the year 2018 when Ukraine severed ties with the CIS FTA—and the trade potential with the EU, which was low throughout the period we studied. Ukraine adjusted and redirected trade, as reflected in the trade potential map with the USA, Canada, China and India becoming overtraded.

Effects from the sanctions were negative throughout the period we studied (Table 3, PPML regression results). Despite the losses incurred, Ukraine's positive economic growth since 2016, combined with the AA/DCFTA, worked to its advantage, resulting in an overall positive effect during the post-annexation period.

Given the minimum necessary time required to adjust production and participate in value chains, we can argue in favor of policies that promote economic growth, trade liberalization, supply chain participation and diversification of exports, imports and supply/production networks. The experience from the 2014 crisis, which led producers and supply chains in Ukraine to search for new trade routes, suggests that exporters should be able to overcome long-term established relationships in value chains and quickly seek alternative routes and substitute destinations. Businesses should already have adapted their production processes, supply chain connectivity and market destinations to minimize the impact of the 2022 conflicts.

For an expeditious recovery of exports, Ukraine should facilitate trade through new agreements or the expansion of existing ones. While it could be argued that the EU's liberalized markets might also serve as an outlet for Ukraine, our trade potential estimates indicate that trade capacity with the EU

has been exhausted. Agreements can help reduce costs and provide viable outlets during periods of crisis or war. They can help stabilize regional markets by ensuring the steady flow of essential goods but also the increased competitiveness of Ukrainian exports in international markets, thereby facilitating economic recovery.

Additionally, connecting to value chains, building safety stocks and securing alternative routes in a global, networked system of production can further assist supply chains, making international cooperation more resilient during turbulent times (Fujita, Nobuaki and Sagara, 2012; Dadakas and Tatsi, 2021). Hartog, López-Córdova and Neffke (2020), who examined Ukraine's opportunities to integrate into European value chains, noted that connecting to Western European value chains was feasible in sectors such as automotive, information technology and other sectors.

The global economy is increasingly interconnected, with complex production and supply chains. Building safety stocks and diversifying suppliers are key strategies for managing supply chain disruptions, maintaining stability, preventing shortages and reducing dependency on any single source or region but also navigating through supply chain challenges and adapting to shifting market conditions. Finally, technological solutions to trade agreements, such as digital trade facilitation tools and supply chain monitoring systems, can also streamline customs procedures, improve transparency and enable more efficient trade processes, thereby supporting Ukraine's export recovery and integration into global markets.

6.3. Broader implications for conflict-affected nations

The effect of the sanctions on exports to third countries was profound with some countries such as Austria, Switzerland, Cyprus, Germany, Egypt, Great Britain, Greece, Croatia, Italy, Latvia, Mexico, Malta, Norway, Poland and Portugal bearing the bulk of the effects. The loss of exports and production implies additional losses for low-income countries in the form of reduced imports of staple commodities. Devadoss and Ridley (2024) argue that military conflicts should not be allowed to disrupt agricultural production in war-torn countries or negatively affect global consumers. A notable example of this principle is the 2000 Trade Sanction Reform and Export Enhancement Act of the USA, which terminated unilateral sanctions on agricultural and medical products and prohibited future sanctions on these items (US Department of the Treasury, 2021; Larch, Luckstead and Yotov, 2024). Many other countries have also lifted sanctions on food and medical products (Drezner, 2011).

While the core idea is that international institutions should facilitate the free trade of agricultural commodities, especially during periods of conflict, the observed increases in futures prices, for example for wheat (30 per cent), corn (10 per cent) (Carter and Steinbach, 2023) and other agricultural commodities, suggest otherwise. Wheat price increases have been observed in importing countries such as Egypt, Iran, Iraq, Uzbekistan, Mexico, Central American and Caribbean countries, as well as in the Middle East-North African region.

These price hikes are attributed to global shortages resulting from disruptions in Ukraine's production and exports. Despite agreements intended to mitigate these effects, the disruptions have, nonetheless, impacted prices.

In this context, we could argue that the reallocation of trade, alongside the AA/DCFTA, the EU solidarity lanes and the Black Sea Grain Initiative, represented a step forward in mitigating losses for developing countries, despite the benefits accrued by Russia. It is crucial that any sanctions implemented be complemented with measures to protect consumers in low-income countries.

7. Conclusions

We employed a structural gravity model (Anderson and van Wincoop, 2003) in conjunction with a PPML approach (Santos Silva and Tenreyro, 2006, 2011; Olivero and Yotov, 2012; Fally, 2015), incorporating intra-country sales (Heid *et al*., 2021). To further analyze the impacts, we applied GEPPML counterfactual scenarios (Anderson *et al*., 2018) to estimate the effects of Russia's 2014 annexation of Crimea on the exports of Russia, Ukraine and other affected nations and to evaluate the resulting changes in trade potential.

Our estimates reveal that both Russia's and Ukraine's agricultural sectors saw benefits in the post-annexation period, with Russia reaping the majority of the benefits. The sanctions imposed on Russia were less effective than anticipated; Russia leveraged the ruble's devaluation, Ukraine's restricted export capacity and redirected trade flows to its advantage. Although Russia's sanctions on Ukraine did impact Ukrainian exports, Ukraine still managed to benefit from economic growth, expanded trade opportunities with the EU due to the AA/DCFTA and redirected trade routes. The limited effectiveness of sanctions may partially explain the ongoing nature of the conflict.

During periods of turbulence, the availability of alternative trade routes and connectivity to supply/value chains is crucial for enabling a swift recovery of production and fostering resilience within supply chains. In cases where intermediate products are significant, adapting supply chains to include multiple partners and diverse locations helps mitigate risks from regional disruptions, thereby enhancing their resilience. Promoting exports and negotiating trade agreements with countries in South America, Turkey, Oceania and select South African nations—where Ukraine's trade potential remains underutilized—can further bolster resilience against external shocks. This strategy reduces dependence on neighboring countries, whose ongoing conflicts could otherwise jeopardize both the agricultural sector and broader international relations.

Future research will aim to incorporate data from the ongoing, post-2022, crisis as it becomes available to evaluate the welfare effects on both producers and consumers, with a focus on differentiating the effects for animal and vegetable products. Additionally, the impact on other sectors of the economy—such as manufacturing, mining and services—will be assessed where possible. Targeted "what-if" scenario analyses for specific industries, using approaches such as GEPPML or agent-based modeling, will also be crucial. These methods offer a low-risk way to test various policy effects within

complex socioeconomic systems and provide valuable insights into which factors most significantly influence desired outcomes through simulation-based analyses.

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