Received: 7 October 2023 | Accepted: 24 May 2024

DOI: 10.1002/aepp.13468

SUBMITTED ARTICLE

AAEA Agricultural & Applied Economics Association WILEY

Global economic effects of war-induced agricultural export declines from Ukraine

Amanda M. Countryman[1] | **Valentyn Litvinov**[2] | **Ivan Kolodiazhnyi**[2] | **Mariia Bogonos**[2] | **Oleg Nivievskyi**[3]

[1]Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, Colorado, USA

[2]Kyiv School of Economics, Center for Food and Land Use Research, Kyiv School of Economics, Kyiv, Ukraine

[3]Graduate Economics Studies, Kyiv School of Economics, Kyiv, Ukraine

Correspondence
Amanda M. Countryman, Department of Agricultural and Resource Economics, Campus Delivery 1172, Colorado State University, Fort Collins, CO 80523-1172, USA.
Email: amanda.countryman@colostate.edu

Funding information
International Agricultural Trade Research Consortium; USDA National Institute of Food and Agriculture, Hatch project COL00232A, accession 7006333; U.S. Agency for International Development

Editor in charge: Alessandro Bonanno

Abstract

The war in Ukraine caused export disruptions that jeopardized the availability and affordability of agricultural and food products around the world. This research employs a computable general equilibrium modeling framework to understand the global economic effects of war-induced agricultural export declines from Ukraine, given the inability to export through the Black Sea. Results show net global welfare losses ranging from more than $5 billion to nearly $20 billion depending on the success of transport through European Solidarity Lanes.

KEYWORDS

agriculture, Black Sea Grain Initiative, food security, international trade, war in Ukraine

JEL CLASSIFICATION

F1, Q1

Over the last two decades, Ukraine and Russia emerged as important global suppliers of agricultural commodities. Both countries are key suppliers of grain, oilseeds, and vegetable oil, while Russia is also an important global supplier of nitrogen fertilizers (Adjemian et al., 2024; Hebebrand & Glauber, 2023). As the world was recovering from the consequences of the

COVID-19 pandemic, Russia began a full-scale invasion of Ukraine in February 2022. The war shocked global agricultural markets and world prices soared through mid-2022 (Ihle et al., 2022; Legrand, 2022). The Black Sea is a critical export supply route for Ukraine, and Black Sea ports were immediately blocked by the Russian naval fleet at the start of the invasion. Ukraine's inability to export through traditional channels forced agricultural products to remain in Ukraine's ports and inland elevators (Martyshev et al., 2023). Concerns regarding agricultural commodity shortages arose as global stocks were low and markets were tight before the war began in Ukraine (Elleby et al., 2023; von Cramon-Taubadel, 2022). Agricultural producers and exporters employed alternative but more costly trade routes through European Solidarity Lanes (ESL) that were introduced by the European Union (EU) in May 2022 to facilitate exports through the western borders of Ukraine by road, rail, and ports on the Danube River (Figure A1) to counteract Russian blockage of Black Sea ports. However, capacity of alternative export routes fell substantially short of the available exportable surpluses. As a result, export costs increased by nearly a factor of six, while grain and oilseed farm-gate prices plummeted below their production costs, and political dialogue to unlock exports from Black Sea ports continued (Martyshev et al., 2023).

Eventually, the Black Sea Grain Initiative (BSGI) was successfully brokered by the United Nations (UN) among Turkey, Ukraine, and Russia to allow for the safe transport of grain and other foodstuffs from Ukrainian ports in the Black Sea (United Nations, 2024a, 2024b). The BSGI launched in the summer of 2022 significantly boosted Ukraine's agricultural exports when the agreement was operational from August 2022 to July 2023. During this period, Ukraine exported 65.1 million metric tons (mmt) of agricultural commodities, including 16.4 mmt of wheat. Prior to the conflict, from 2019 to 2021, Ukraine's average wheat exports stood at 19.4 mmt, with African countries accounting for 38 to 45% of export supplies[1] (Balana et al., 2023; Breisinger, Kirui, et al., 2023a; Breisinger, Diao, et al., 2023b; Breisinger, Khouri, et al., 2023c; ITC, 2024; Kurdi et al., 2023). Many of these countries faced levels of moderate to severe food insecurity, with Ukrainian wheat playing a crucial role in their domestic food supply. For instance, food insecurity affected 39.8% of the population in Libya, where Ukrainian wheat accounted for 43.1% of total domestic supply, and the same story holds in several other food insecure African countries[2] (FAO, 2024a; ITC, 2024). International concerns regarding the potential food security impacts of the war in Ukraine were rooted in the fact that Ukraine export supplies were crucial for the import needs of vulnerable, food insecure countries, and the absence of Ukrainian grain exports could potentially lead to both import shortages and food price shocks.

During the BSGI period, August 2022 through July 2023, the total quantity of wheat exported from Ukraine to Africa was 2.6 mmt. In comparison, exports before the war were 8.4 mmt from August 2020 through July 2021. However, import statistics for African countries during the BSGI period did not indicate a decline in total wheat import quantities, suggesting that Ukrainian wheat was substituted through trade diversion. The data show growth in wheat exports to Africa from the United States, Argentina, Turkey, Brazil, and France increased after the war began but before the BSGI, and then decreased after introduction of the BSGI. Exports from the Netherlands, Lithuania, and Poland followed a similar pattern, although this may indicate re-exports from Ukraine (FAO, 2024a; ITC, 2024).

The primary factor contributing to heightened food insecurity risks in sensitive regions in Africa, and globally, was the surge in global wheat prices, which nearly doubled from February to June 2022. For example, Black Sea milling wheat increased from 321.20 to 414.39 USD/mt, signaling anticipated global supply shortages. With the implementation of the BSGI, Black Sea

milling wheat prices decreased from 414.39 USD/MT in February 2022–337.65 USD/MT in August 2022, and by the end of BSGI, international wheat prices had returned to 2021 levels[3] (Figure A2) (FAO, 2024b). Although it is difficult to quantify the effect of the BSGI on international and domestic prices given changes in other market forces during the same period (Goyal & Steinbach, 2023), the transport corridor facilitated sustained global food supplies. It is important to note that the BSGI also had humanitarian purposes unrelated to Ukraine.[4] Furthermore, the introduction of BSGI also helped prevent a scenario where major global exporters would disproportionately benefit, as the initiative minimized the gap between global demand and supply (ITC, 2024).

Termination of the BSGI in July 2023 again limited Ukraine's export capacity to more costly ESL. Concurrently, intensified shelling of the Danube River ports weakened the transship capacities of the ESL, and tensions arose between Ukraine and neighboring countries (primarily Poland) over increased grain exports into the EU through ESL routes. This also triggered temporary import restrictions on grain from Ukraine imposed by the EU Commission, given concerns about further agricultural exports from Ukraine (EU Commission, 2023a). Further success of Ukraine's military in the Black Sea, however, helped to re-establish shipping of agricultural and nonagricultural products from Black Sea ports (Glauber, 2024). By late fall 2023 and in the beginning of 2024, monthly export volumes rebounded significantly and even surpassed prewar levels. However, the complexities of continued war and concerns regarding Ukraine's export potential maintain food security concerns with import-dependent developing countries the most vulnerable (Martin & Minot, 2023). In this regard, the role and impact of the ESL capacity and functionality is important to understand quantitatively given its importance for alternate transport in the event of potential interruptions of the Black Sea route.

This research employs a computable general equilibrium (CGE) modeling framework to investigate the economywide effects of war-related disruptions in agricultural exports from Ukraine depending on whether the ESL capacity is weak or strong. This manuscript proceeds as follows. First, we provide a description of the importance of Ukraine in global agricultural markets including agricultural production and exports, as well as changes in transport routes from Ukraine. We then highlight studies of the economic effects of the war in Ukraine. Next, we describe the methods, data, and export scenarios and analyze results. We provide a comparison of simulated and observed changes in Ukrainian exports and domestic prices and conclude with a discussion of key findings and implications of this research.

The importance of Ukraine in global agricultural markets

Historically, Ukraine has been considered a breadbasket for neighboring and more distant regions. Ukraine has one-third of the world's most fertile black soils and a relatively flat landscape that allows for higher yields and larger fields that contributed to the development of Ukraine's crop-based agriculture. Approximately 80% of arable land in the country is used to produce cereals, oilseeds, vegetables, and other annual crops (State Statistics of Ukraine, 2020; World Bank, 2021). Since 1992, crop production has dominated Ukrainian agriculture, and we show changes in production and exports of crop and livestock commodities in Figures A3 and A4. In 2021, primary agriculture contributed almost 10% of Ukraine's Gross Domestic Product (GDP), 18% of employment, and 44% of total export value. When up- and downstream sectors are accounted for, the share of agriculture increases to approximately 20% of Ukraine's GDP (von Cramon-Taubadel & Nivievskyi, 2023). Ukraine has signed 12 bilateral and multilateral

trade agreements since 1995, became a member of the World Trade Organization in 2005, and established a Deep and Comprehensive Free Trade Area (DCFTA) with the EU in 2016 (EU Commission, 2024). Concurrently, import tariffs and many specific tariffs on nonsensitive agricultural and food products were reduced to Most-Favored Nation (MFN) levels. Ukraine's continued efforts to expand trade relationships through trade policy liberalization led to expanded exports of agricultural products since the mid-1990s.

Before the full-scale Russian invasion, Ukraine supplied approximately 50% of global sunflower oil, nearly two-thirds of sunflower meal exports. While sunflower oil is processed for human consumption, sunflower meal as a by-product is used as feed for livestock production. The main destination markets for sunflower oil were China (48%), the EU (25%), and Turkey (7%). Currently, sunflower oil is consumed in 48 countries around the world, with the biggest consumption in the EU, India, and China[5] (IndexMundi, 2023). Ukraine was the third largest exporter of rapeseed, and seventh largest exporter of soybeans before the war. The country ranked fourth in corn exports, with top destinations including China, EU, Egypt, Iran, and Turkey.

Ukraine was the seventh largest wheat exporter before the war and was expected to be the fifth largest wheat exporter in the 2021/2022 marketing year (USDA, 2022a). Middle East and North African countries highly depend on Ukrainian wheat with Egypt, Indonesia, Turkey, Pakistan, and Bangladesh as the main export destinations (FAO, 2024a; Smith, 2023). For example, in 2021 Ukraine supplied 35% of total wheat imports in Egypt where wheat and wheat products comprised 31.5% of daily consumption[6] (FAO, 2024a; International Trade Centre, 2024). Lebanon imported 61.5% of its wheat from Ukraine in 2020, wheat and wheat products account for 31.8% of daily caloric consumption, and the price of bread increased by an astonishing 70% after the blockade of Ukrainian exports (IPES-FOOD, 2022; OEC, 2021).

Other African countries are also import dependent and exposed to high price volatility, including Sudan, Kenya, Ethiopia, and Somalia as the most vulnerable (Abay, Breisinger, et al., 2023b; Breisinger, Kirui, et al., 2023a; Breisinger, Diao, et al., 2023b). Other countries, like Burundi and Rwanda, indirectly depend on Ukraine's sunflower oil through re-exports from Egypt (EU Commission, 2022b). The prices of vegetable cooking oil, bread, and wheat flour have increased dramatically along with fuel prices and the cost of living overall. West Africa and the Sahel region are also negatively affected by high commodity prices and scarcity with up to 10 million people at risk to become food insecure due to the war in Ukraine. Several Asian countries including Pakistan, Bangladesh, and Indonesia have experienced similar challenges given import dependency on wheat supplies from Ukraine and Russia to meet domestic demand (Mamun & Imrul Kabir, 2023; USDA, 2022b). Arndt et al. (2023) find that an additional 27.2 million people have been pushed into poverty, and another 22.3 million people face hunger as a direct result of the war. The ongoing war in Ukraine jeopardizes global food security and puts pressure on commodity markets (Glauber, 2023).

Global agricultural commodity prices nearly doubled from February to June 2022 following the Russian invasion of Ukraine and then decreased to values below prewar levels in fall 2023 but remain relatively high (Glauber, 2024). Inflation has been greater than 5% for almost all low- and middle-income countries (FAO, 2023). Trade disruption is another result of the war, as it became riskier to supply from Ukraine and Western sanctions were imposed on Russian goods in response to the invasion. The intensive fighting has been localized to the Eastern and Southern parts of Ukraine (Kherson, Zaporizhzhia, Donetsk, Luhansk Oblast, and Crimea); however, regional centers throughout the country and critical infrastructure, such as roads, ports, storage facilities, and power stations continue to suffer from Russian missile and drone

strikes. As of June 2023, the total estimated damages to Ukraine were $150.5 billion,[7] which is close to the value of Ukraine's 2022 GDP.

Ukraine's agricultural potential has been substantially hit by the war with no clear production and export recovery time horizon. Nearly 20% of Ukraine's territory has been occupied by Russia since February 2022, and nearly 28% of Ukraine's agricultural capital assets ($8.7 billion) have been destroyed by the war.[8] In addition, more than 174,000 square kilometers (30% of Ukraine's territory) suffers tremendous and long-term pollution and damage by explosive objects, mines, remnants of missiles, and missile complexes. This land is dangerous for civilians and is no longer suitable for any kind of economic activity including agricultural production without costly remediation.[9] Lost territory and damage to the agricultural sector translates into millions of tons of forgone output and exports. The Russian army and supported parties have reportedly stolen 6 million tons of grain from the occupied territories in Ukraine since the beginning of the war (U.S. Office of the Director of National Intelligence, 2023). Moreover, recent investigation proved that Russian entities have been exporting stolen agricultural products from Ukraine's occupied territories (Molfar, 2023). The most substantial drop in production in Ukraine is recorded for barley, as production fell by 38.8% in 2022 compared to 2021, while production for wheat and sunflower seeds decreased by 33.3% and 30.9%, respectively. Corn production was less negatively affected and decreased by 18.3% in 2022 compared to 2021. This is mainly because the corn belt of Ukraine is in the center of the country, above the occupied South and below the liberated North of Ukraine. The harvest for other annual crops was 17.4% lower in the 2022 calendar year than 2021 (Neyter et al., 2022). Overall, Ukraine planted 19.5 million hectares of arable land in the 2022/2023 season compared to 20.8 million hectares in 2021/2022 and 28.4 million hectares in 2020/2021 (MAPF, 2023; Ukrainian Agribusiness Club, 2022).

In addition to destruction from war, agricultural producers suffer tremendously from a domestic price crisis. Severely reduced export capacities and a lack of alternative export routes increased logistics costs that eventually depressed farm-gate prices in Ukraine approximately by a factor of two (see Figure A5) (Nivievskyi & Neyter, 2024). Depressed domestic prices for export-oriented commodities and losses from the 2022 and 2023 harvests led to forgone revenues and additional costs of approximately $31.5 billion. Furthermore, there was a shortage of inputs when Ostchem, one of the major domestic fertilizer producers located in an occupied region, decreased production by more than 66%, from 5.3 million tons in 2021 to 1.76 million tons in 2022 (SuperAgronom, 2023). Even though world market prices for fertilizers decreased 1.5 times in some countries from 2021 to 2023, fertilizer expenditures by Ukrainian agricultural producers increased 2.4 times on average over the same period.[10] The combined effects of occupied land, war-related damages, increased fertilizer prices, and decreased input availability led to decreased planting and yields in Ukraine.

Transport from Ukraine: Black Sea Grain Initiative (BSGI) and European Solidarity Lanes (ESL)

The UN and Turkey moderated the BSGI with Ukraine and Russia to make large, blocked stocks of grain in Ukraine available for import-dependent countries. The BSGI established a corridor to transport grain from Ukraine's three deep-water Black Sea ports: Odesa, Chornomorsk, and Pivdennyi (United Nations, 2024). The corridor allowed increased agricultural exports from Ukraine starting in August 2022; however, the corresponding effects on

domestic prices were minor and only marginally improved domestic producer incomes (Nazarkina & Nivievskyi, 2023). While the BSGI facilitated increased exports, transport costs remained high and close to pre-BSGI levels while domestic prices stayed depressed. Moreover, Russia consistently undermined trust regarding the functioning of the BSGI that kept risks and costs of grain corridor shipments high by delaying vessel inspections and persistent threats to leave the agreement (UkrAgroConsult, 2023). Eventually, Russia withdrew from the BSGI in late July 2023 (UN, 2023).

In May 2022, the EU Commission launched the Solidarity Lanes Action Plan known as the European Solidarity Lanes to facilitate alternative export routes through the western borders of Ukraine, by road, rail, and river ports on the Danube River (EU Commission, 2022c). This huge intragovernmental project contained urgent and medium run measures to address transport logistics bottlenecks between the EU and Ukraine. Urgent measures included making additional freight rolling stocks, vessels, and lorries available to match demand, prioritizing capacity of transport networks and transshipment terminals for Ukraine's exports. Customs operations were also applied at maximum flexibility and speed. Medium term measures included a new road transport agreement between the EU and Ukraine, a proposal to extend the Trans-European Transport Network to Ukraine, and the establishment of a Joint Coordination Platform to improve the flow of trade. So far, close to $2 billion of investments were mobilized to facilitate the ESL and exports from Ukraine. As of September 2023, the ESL facilitated 95 mmt of exports from Ukraine, including 53.2 mmt of agricultural products (EU Commission, 2023b). Since the dissolution of the BSGI, exports of agricultural commodities by rail through the ESL have reached approximately 1 million tons per month, and river port export capacities increased to approximately 2.8 million tons per month (Figure A6). However, right after the BSGI dissolution, Russia began attacking the Danube port infrastructure causing further increased export costs. Overall, agricultural export costs increased threefold after the invasion: from prewar $30 to $40 per ton, then peaking at about $200 per ton early in 2022 before stabilizing at $125–150 per ton in the beginning of October 2022, as illustrated by the difference in the world price and domestic price for milling wheat in Figure A2. With increased shelling of river ports and the absence of the BSGI, export costs increased by approximately 10% and the ESL became critical (Meredith, 2023). Moreover, at about the same time as the BSGI dissolution, tensions between Ukraine and neighboring countries over increased grain exports into the EU intensified and first resulted in import restrictions imposed by individual countries including Poland and Hungary in April 2023, that later led to general, temporary EU restrictions on imports imposed in May 2023 that lasted until September 15, 2023 (EU Commission, 2023a). However, further success of Ukraine's military in the Black Sea helped the country to re-establish shipping of agricultural and nonagricultural products from Black Sea ports (Glauber, 2024). By late fall 2023 and the beginning of 2024, monthly export volumes had rebounded significantly and even surpassed prewar levels.

Despite the BSGI and efforts to improve trade through the ESL, agricultural exports from Ukraine have been stifled since the start of the war. Wheat exports dropped by nearly 39% and other crop exports (such as tomatoes, onions, cabbage, and other vegetables) decreased by 49% from 2021 to 2022. However, oilseed exports unexpectedly doubled over the same time frame. Typically, more than 95% of sunflower seeds are crushed then exported as meal and oil, but sunflower seed exports increased in 2023 is because of relatively high export prices for seeds relative to domestic crush prices (USDA, 2022b). Selling seeds for local crush was less profitable than exporting, even with considerably increased transportation costs and rail congestion at the western borders (MAPF, 2023). This contributed to a 15% decrease in total vegetable oil

exports[11] and a reduction in domestic vegetable oil stocks[12] (USDA, 2023). Despite challenges, corn remains the dominant export crop, as illustrated in Figure A7, due to its large stocks and proximity to primary export destinations, notably EU countries. The share of wheat in total exports has been increasing gradually since the start of July 2023. However, wheat exports dropped significantly in 2022–2023 compared to 2021. Ukraine's exports did not reach prewar levels even with increased exports through the BSGI and ESL. Global agricultural prices were already high, and supplies were tight before the Russian aggression given trade disruptions from COVID-19 and decreased world supplies from drought. Commodity prices substantially increased after 2020 but skyrocketed after the onset of the Russian invasion (see Figures A8 and A9), when the Black Sea and Azov Sea ports of Ukraine were either occupied or blocked by the Russian naval fleet, thereby triggering increased commodity prices given concerns about global food security (Ihle et al., 2022).

Related literature

The literature on the economic effects of the war in Ukraine is growing as the crisis continues. Methods employed include general equilibrium modeling, partial equilibrium (PE) modeling, and various econometric analyses. Studies can generally be described by three key thematic areas including a focus on agriculture and food security, energy markets, and financial markets. Bullock et al. (2023) use an Equilibrium Displacement Model to investigate the price impacts of increased exports through the BSGI and find decreased prices for wheat and corn that benefit import dependent countries. Poursina et al. (2024) employ time series analysis and find that the BSGI brought a 7.9% reduction in global wheat prices that largely benefits developing countries in the Middle East and North Africa. Grant et al. (2023) investigate the effects of decreased exports from Ukraine using bilateral trade data and describe the improvements made through the opening of the BSGI, highlighting that time will be needed to rebuild Ukraine's export infrastructure after the war concludes. Rose et al. (2023) use the Global Trade Analysis Project (GTAP) model to investigate the effects of Ukrainian grain export disruptions at the start of the war and find a $859 million decrease in Ukraine's GDP. Beckman and Ivanic (2023) employ the GTAP model to investigate scenarios including agricultural production losses, export losses, changes in labor supply in both Russia and Ukraine, and decreased domestic energy prices in Russia in 2022. The authors find that decreased exports from Ukraine are the key drivers of global economic impacts with price increases ranging from less than 1% to 11% across sectors. Alternatively, He et al. (2023) employ different scenarios using a PE model and find that the impact of increased global fertilizer prices on commodity prices is larger than the impacts of decreased agricultural exports from Ukraine. Feng et al. (2023) use a Structural General Equilibrium Model to examine the impact of war-induced agricultural output decreases in Ukraine and find that agricultural prices increase by 10%–30% with severe effects on import-dependent countries. Laber et al. (2023) use a multilayer network model to investigate the impacts of the war on food availability and emphasize the interconnectedness of the global food production network, which is consistent with other studies that show increased alignment and interconnectedness of commodity markets during the war (Alam et al., 2022; Aliu et al., 2023; Ihle et al., 2022). Liadze et al. (2022) employ a structural econometric model and find a 1% ($1.5 trillion) decrease in global GDP in 2022 with Europe being the most affected due to energy and food dependencies on Ukraine and Russia. Arndt et al. (2023) describe how agricultural systems

and poverty levels are vulnerable to fuel and fertilizer price spikes, while food insecurity and diet quality worsen with rising food costs.

The studies on war impacts related to energy markets provide insights into the multifaceted global economic consequences of the war, highlighting the significance of energy dependence, trade dynamics, and government policies in shaping outcomes (Chepeliev et al., 2022; Nerlinger & Utz, 2022; Steffen & Patt, 2022; Yagi & Managi, 2023; Zhou and Wang, 2023). Several studies also show the negative effects on national economies resulting from increased energy prices during the war (Ajeigbe, 2023; Chowdhury et al., 2023; Colgan et al., 2023; Liadze et al., 2022). Research on the impact of the war on financial markets reveals strong negative reactions immediately after the invasion with increased volatility across nearly all asset classes with varying effects across markets (Babar et al., 2023; Beraich et al., 2022; Boubaker et al., 2022; Bougias et al., 2022; Boungou & Yatié, 2022; Izzeldin et al., 2023; Karkowska & Urjasz, 2023; Taera et al., 2023). The comprehensive and growing body of economic research highlights the effects of the war on agriculture and food security, energy markets, and financial markets. While there are numerous studies on the effects of the war, and a few that investigate the market impacts of transport through the BSGI, this is the first paper to our knowledge that investigates the effects of war-induced decreases in exports from Ukraine given varying success of the ESL. This research contributes to the literature on the effects of the war in Ukraine on agricultural markets and provides important insights regarding the importance of well-functioning transport routes for agricultural exports.

Modeling framework

We employ the GTAP Version 7 CGE model and GTAP 11 database to simulate the global effects of war-induced disruptions in agricultural exports from Ukraine with two scenarios of transport capacity through the ESL (Aguiar et al., 2022; Corong et al., 2017). CGE models include interactions between producers, consumers, investors, households, and governments, and are useful to characterize linkages between sectors and investigate policies that have economywide impacts such as the export shocks addressed in this research. The GTAP modeling framework employed for this work has been used widely to investigate the impacts of agricultural supply chain shocks and changes in bilateral trade. The GTAP model assumes perfect competition with constant returns to scale, and regional household demand is described by a Constant Difference of Elasticities (CDE) specification. Bilateral trade is determined by the Armington import demand specification, where demand is first allocated between domestically produced goods and an import composite, followed by regional import sourcing of the composite import (Armington, 1969). Full documentation of the GTAP model is available in Corong et al. (2017). The GTAP 11 database is comprised of 160 regions and 65 economic sectors that we further aggregate to 12 geographic regions and 13 sectors focused on food and agricultural products (see Tables A1 and A2). We update the GTAP 11 database from the 2017 base year to 2021 given changes in macroeconomic variables including population, investment, and GDP, following the literature (Beckman & Countryman, 2021; Boulanger et al., 2016; Diffenbaugh et al., 2012; Hertel et al., 2010). Data on population, investment, and GDP are from the World Bank World Development Indicators database and from the International Monetary Fund (IMF).

Ukraine faced substantial export losses when ports were blocked by the Russian naval fleet for 6 months after the start of the Russian invasion, and about 20 million tons of grain

remained in Ukraine until the BSGI was put in operation in August 2022. Inability to export from Black Sea ports, which was the route for more than 90% of Ukraine's agricultural exportable surpluses before the war, forced traders to seek alternative and more costly export routes through inland waterways, railways, and over land. Increased transport and logistics costs had negative effects on Ukraine's agricultural export volumes and changed destination markets. We model two scenarios to simulate the effects of changes in exports from Ukraine after the dissolution of the BSGI, conditioned on the performance of the ESL for Ukraine (i.e., with or without Russian attacks on ESL infrastructure). Scenario I (SI): Weak ESL assumes that Russia continues attacking river ports and other logistics infrastructure in Ukraine, causing agricultural export capacities to decline to the levels observed in the first 3 months after the start of the full-scale invasion. SI assumes no exports through the BSGI routes and a limited ESL capacity equal to 1 mmt per month of agricultural product exports from Ukraine, equal to 12 mmt per year, approximately 20% of Ukraine's prewar monthly exports. This is an annualized extrapolation of the export flows from Ukraine observed from March through May 2022.[13] Scenario II (SII): Strong ESL assumes full transshipment capacity at the levels observed from June 2022 through December 2022 when the ESL was well-functioning. SII assumes that total agricultural exports from Ukraine are approximately 2.8 million tons per month, or 30 million tons per year. Both scenarios model changes in agricultural exports from Ukraine without access to Black Sea transport routes conditioned on the export capacity of the ESL assuming either severely limited ESL capacity due to attacks from Russia (SI) or well-functioning capacity of ESL without attacks from Russia (SII). We do not consider other impacts of the war such as further destruction of the Ukrainian agricultural sector and output. SI can be considered a worst-case scenario while SII is a best-case scenario for agricultural exports from Ukraine with continued war.

SI described in Table 1 shows the percentage changes in export volumes by sector from Ukraine to trade partners that would have occurred in 2022 if agricultural exports were limited to 1 million tons per month at most compared to 2021 when export capacity functioned at full capacity. Exports to all partner regions decreased substantially for all sectors except for grain to the Former Soviet Union (FSU) region (which in this paper excludes, Russia, Belarus, and Ukraine), wheat exports to Central and South America, oilseed exports to FSU, Europe (EU and Balkan countries), Middle East and North Africa (MENA), and Southeast Asia, livestock and meat exports to five out of 11 regions, and processed food exports to Europe and Southeast Asia.

While we model bilateral changes in exports from Ukraine, it is important to consider the changes in total exports by sector. For SI: Weak ESL, wheat exports decline by nearly 98%, grain (mostly corn) exports decrease by 79%, other crop exports decrease by almost 74%, and processed food exports decrease by more than 23%. While there is a 28% increase in oilseed exports, as producers opted to export seeds rather than sell for domestic crush, this does not fully compensate for the more than 81% decrease in vegetable oil exports. European countries bordering Ukraine became the main export destinations for agricultural products during the first 3 months after the invasion. However, exports to Europe were lower than prewar levels for all agricultural sectors except oilseeds and livestock and meat products. Grain exports to European countries decreased by 56%, while wheat and other crop exports decreased by 60% and nearly 75%, respectively. Oilseed exports to FSU and MENA unexpectedly doubled and increased by more than 40% to Europe and Southeast Asia because export prices for oilseeds exceeded comparable domestic crush prices, causing producers to export oilseeds rather than produce vegetable oil for export. Grain exports decreased by more than 86% for all regions except Europe and FSU, and vegetable oil exports to all partners dropped by more than 68%.

TABLE 1 Percentage changes in bilateral agricultural exports from Ukraine for Scenario I: Weak European Solidarity Lanes.

% change in quantity	Grains	Other crops	Wheat	Oilseeds	Livestock and meat	Vegetable oil	Processed food
Russia and Belarus	−90.63	−90.90	0.00	−93.58	−82.23	−99.62	−91.64
Former Soviet Union	11.15	−42.81	−56.09	122.98	−19.97	−63.61	−38.07
Europe	−56.34	−74.52	−59.57	48.14	35.34	−74.31	22.75
Middle East North Africa	−86.80	−56.07	−97.91	108.50	1.50	−68.45	−42.94
Central and Southern Africa	−96.50	−91.43	−98.73	−11.24	−61.65	−86.51	−83.52
China and Hong Kong	−90.25	−69.21	−97.31	−47.61	−55.73	−92.46	−73.09
Southeast Asia	−86.91	−70.57	−99.50	40.99	220.77	−74.27	4.58
South Asia	−95.07	−86.64	−98.95	−85.42	−1.81	−91.15	−69.08
Rest of Asia and Oceania	−98.88	−79.28	−97.67	−77.67	−66.92	−92.70	−81.27
North America	−99.55	−89.97	−99.99	−53.98	4.96	−80.41	−24.74
Central and South America	−98.26	−96.92	−100.00	−100.00	343.63	−94.74	−72.97
Total exports	−79.1	−73.6	−97.6	28.2	−6.0	−81.4	−23.4

Source: Authors' calculations based on data from MAPF (2023).

Exports to FSU have grown substantially; however, it is essential to note that Ukraine's exports to these countries remained relatively low in absolute values in 2021. Consequently, this large percentage increase in exports corresponds to relatively small changes in absolute terms.

The MENA region merits particular attention. Despite substantial distance and logistics costs, exports from Ukraine have not completely halted during the war. Exports to MENA decreased for grains (87%), other crops (56%), wheat (98%), vegetable oil (68%), and processed food (43%). However, oilseed exports to MENA more than doubled, wherein the demand from Turkey was a major driving force along with oilseed prices relative to crush. Danube River exports and transit through the ESL reached MENA countries through Turkey as the key regional trader, while exports to other regions largely decreased. Despite the war, Ukraine still exported products to Russia and Belarus in spring 2022, and we allow for these minor export flows in both scenarios.

SII: Strong ESL assumes no transport from Ukraine through BSGI routes and that the ESL functions at its full technical capacity as was observed before the Danube River transshipment capacity was constrained by damages from Russian bombardments. SII described in Table 2 shows the sector-specific annual percentage changes in export volumes from Ukraine to trade partners that would have occurred in 2022 with well-functioning ESL capacity of up to 2.8 million tons per month without access to the BSGI routes. The ESL were used at their full transport capacity by Ukrainian exporters until July 2023, on top of the functioning BSGI

TABLE 2 Percentage changes in bilateral exports of agricultural commodities from Ukraine for Scenario II: Strong European Solidarity Lanes.

% change in quantity	Grains	Other crops	Wheat	Oilseeds	Livestock and meat	Vegetable oil	Processed food
Russia and Belarus	−90.63	−90.90	-	−93.58	−82.23	−99.62	−91.64
Former Soviet Union	383.28	−42.81	997.80	259.65	−19.97	65.40	−38.07
Europe	45.49	−74.52	573.82	93.31	35.34	7.48	22.75
Middle East North Africa	−69.94	−56.07	−68.50	178.56	1.50	7.77	−42.94
Central and Southern Africa	−84.76	−91.43	−95.78	43.17	−61.65	−47.33	−83.52
China and Hong Kong	−72.82	−69.21	−32.87	−15.50	−55.73	−83.10	−73.09
Southeast Asia	−43.09	−70.57	−99.54	127.40	220.77	16.94	4.58
South Asia	−78.58	−86.64	−89.12	−88.97	−1.81	−82.54	−69.08
Rest of Asia and Oceania	−227.74	−79.28	−96.77	−63.98	−66.92	−66.80	−81.27
North America	−98.04	−89.97	−99.82	−25.78	4.96	−10.94	−24.74
Central and South America	−92.45	−96.92	−100.00	−100.00	343.63	−76.09	−72.97
Total Exports	−37.2	−49.2	−65.7	68.0	−6.0	−32.7	−23.4

Source: Authors' calculations based on data from MAPF (2023).

routes. At the same time, exporters sought alternative transport routes through ESL from 2022 through 2023 because of the overall distrust in the BSGI and delay of shipments via lengthy inspection processes imposed by Russia. In 2022, 50.9 million tons (4.2 tons per month on average) of agricultural exports were shipped from Ukraine (Slovodilo, 2023). To obtain data on exports via the Strong ESL in 2022, we subtract the quantities exported through the BSGI from total exports by commodity and country in the same year (MAPF, 2023). The percentage changes are then calculated by comparing Ukraine's export quantities through ESL by commodity and destination region in 2022 compared to 2021. As expected, total exports from Ukraine decline compared to prewar levels, but are much larger in SII than in SI because of the larger export capacity through ESL when Danube River ports are available despite inability to export through the BSGI. European countries bordering Ukraine continue to be the main export destinations for agricultural products in both scenarios due to geographic proximity when shipping through the ESL. Under SII, exports to Europe increase for all sectors except other crops. Wheat exports increase by a dramatic 574% compared to 2021, while grain and oilseed exports also increase by 45% and 93%, respectively. Exports to FSU also increase, but from relatively low levels. Just as in SI, the large relative increase in exports corresponds to relatively small trade volumes that are much lower than the export volumes to Europe and MENA. Exports to other regions increase, implying that European countries were not only the primary destinations, but also served as transition routes to MENA and other countries in Africa and Asia. Total exports

to MENA increased for oilseeds (179%), livestock and meat (2%), and vegetable oils (8%). Oilseed exports to Africa increased by 43%, while vegetable oil exports decreased by 47% (MAPF, 2023).

RESULTS

We simulate changes in wartime agricultural export flows from Ukraine given the dissolution of the BSGI conditioned on performance of the ESL. Results for both scenarios demonstrate net negative global impacts in terms of GDP and welfare. First, we describe the results for SI, including simulated changes in aggregate exports, GDP, domestic production, and prices. Then we discuss the changes in GDP and welfare outcomes in both scenarios and contrast results for changes in production and prices across regions to understand how the negative impact of the war on Ukraine's agricultural exports is moderated by the capacity or performance of the ESL.

Other countries increase exports to replace missing supplies from Ukraine after the beginning of the Russian invasion. Table 3 shows percentage changes in aggregate exports by sector for regions outside Ukraine for SI. Exports grow in most countries and across various sectors, except for oilseeds. This is because our simulation reflects a decline in exports from Ukraine for all products except oilseeds because Ukraine increases seed exports rather than sell for domestic crush as described previously. The largest increase in grain exports is simulated for FSU (23%), Russia and Belarus (21%), MENA (18%), Europe (15%), Rest of Asia and Oceania (14%), and Central and South America (13%). The second largest increases for wheat exports are from South and Southeast Asia, though they are not important wheat suppliers. There is a 10% increase in wheat exports found for the Rest of Asia and Oceania region that includes Australia, which is a key global supplier of wheat. It is important to note that simulated increases in grain and wheat exports from Russia and Belarus occur in the absence of any trade policy restrictions modeled.

Table 4 shows the simulated outcomes for percentage changes in GDP and domestic production for SI. Poorly functioning ESL leads to simulated GDP decreasing by more than 10% in Ukraine compared to the base year and from 0.01% to 0.08% for other regions except for the Americas and the Rest of Asia and Oceania region. Agricultural production levels are endogenously determined in the model in response to exogenously specified decreased agricultural exports from Ukraine for each scenario. We hold nonagricultural production fixed in Ukraine so that domestic adjustments occur across agricultural and food sectors. Simulated results for Ukraine demonstrate a 95% decrease in wheat production, 76% decrease in vegetable oil production, 73% decrease in grain production, 21% decrease in output of livestock and meat products, 16% decrease in processed food, 15% decrease in oilseed output, and 10% decrease in production of other crops. While the simulated production declines are substantial, it is important to note that this is primarily due to Ukraine's substantial export-oriented crop production that suffers from severely decreased exports. Oilseed output decreases in Ukraine despite simulated increased exports because of substantially reduced vegetable oil production and exports. Other countries reallocate resources and economic activity in response to decreased global supply due to reductions in agricultural exports from Ukraine, and changes in domestic production reflect changes in bilateral exports. Production increases for wheat, grains, and vegetable oils in all regions outside Ukraine to compensate for the simulated decrease in Ukrainian exports. Production of other crops also grows in all other regions except Southeast Asia. Notably, the most substantial changes in production are simulated for grain, with output increasing by 9% in the

TABLE 3 Percentage changes in regional aggregate exports for Scenario I: Weak European Solidarity Lanes.

Sectors	Russia and Belarus	Former Soviet Union	Europe	Middle East North Africa	Central and Southern Africa	China and Hong Kong	Southeast Asia	South Asia	Rest of Asia and Oceania	North America	Central and South America
Grains	20.88	23.26	15.28	17.9	5.75	5.33	5.73	8.13	14.41	5.45	12.67
Other crops	−2.61	−0.18	0.03	0.21	0.12	0.54	−0.19	0.05	−0.03	0.04	−0.4
Wheat	8.05	5.65	4.23	8.33	4.4	8.28	11.04	20.48	10.29	7.29	4.11
Oilseeds	−3.23	−1.52	−1.05	−3.67	−0.92	−1.6	0.62	−1.22	0.96	0.45	−0.18
Livestock and meat	0.6	0.03	−0.14	0.27	0.43	0.25	−0.2	−0.13	0.07	0.18	−0.61
Vegetable oil	4.14	5.48	3.76	5.99	1.81	1.78	3.5	2.76	3.24	1.57	3.42
Processed food	0.9	0.52	−0.01	−0.01	0.01	0.21	−0.1	0.1	0.16	0.15	−0.21

Source: Authors' presentation using simulation outcomes.

TABLE 4 Percentage changes in Gross Domestic Product (GDP) and output for Scenario I: Weak European Solidarity Lanes.

GDP, % change	Ukraine −10.06	Russia and Belarus −0.02	Former Soviet Union −0.08	Europe −0.01	Middle East North Africa −0.07	Central and Southern Africa −0.01	China and Hong Kong −0.01	Southeast Asia −0.01	South Asia −0.03	Rest of Asia and Oceania 0.00	North America 0.00	Central and South America 0.00
Grains	−72.83	6.91	2.67	7.22	8.03	0.41	0.69	0.28	0.28	9.06	1.04	4.28
Wheat	−94.78	5.97	1.81	2.01	2.41	1.52	0.04	3.70	1.42	8.70	4.25	1.78
Vegetable oil	−75.79	2.79	3.00	2.41	3.24	0.39	0.35	2.18	2.58	0.60	0.29	1.52
Other crops	−9.68	0.12	0.00	0.05	0.07	0.01	0.02	−0.07	0.00	0.02	0.01	−0.13
Oilseeds	−14.79	1.40	−0.21	0.52	−1.21	−0.04	0.24	1.40	1.03	0.64	0.38	0.40
Livestock and meat	−20.93	0.11	0.24	−0.07	−0.03	0.02	0.00	−0.07	−0.03	0.00	0.01	−0.07
Processed food	−15.61	0.25	1.02	−0.03	−0.04	0.04	0.00	−0.06	−0.01	0.03	0.01	−0.04

Note: The first row in the table shows the percentage change in GDP across regions and the remaining table values show changes in sectoral output across regions for Scenario I.
Source: Authors' presentation using simulation outcomes.

Rest of Asia and Oceania, 8% in the MENA region, and exceeding 7% in Europe. Wheat production also increases across all regions, with the most substantial increase of nearly 9% occurring in the Rest of Asia and Oceania region. The regional consequences of reduced exports from Ukraine in the livestock, meat, and processed food sectors are minimal, except for a marginal 1% rise in domestic processed food production within the FSU region. This is primarily because Ukraine's role in global exports of livestock, meat, and processed food is relatively small, resulting in negligible production adjustments across regions outside Ukraine. The 1% increase in processed food production in FSU is in tandem with increased domestic production of primary agricultural products including grains (2.7%), wheat (1.8%), and vegetable oil (3%) that are used as inputs in the processed food sector.

Figure 1 shows percentage changes in domestic prices across regions and sectors for SI: Weak ESL. As expected, prices for agricultural products fall substantially in Ukraine when exports decrease. Prices decline in Ukraine by 16% for wheat, nearly 18% for processed food, and by more than 20% for remaining sectors including vegetable oil, oilseeds, grains, other crops, and livestock and meat. Domestic prices increase by less than 1% for all agricultural sectors across regions outside Ukraine except for negligible decreases in the domestic prices of oilseeds and vegetable oil in MENA. Although domestic price increases are modest, the fact that prices are changing across almost all sectors and regions gives a considerable aggregate impact reflected in changes in GDP and welfare. The explanation is rather intuitive: Ukraine's exports are not fully replaced; therefore, agricultural production and prices are higher across regions outside Ukraine.

In summary, the findings of the SI reveal that a reduction in agricultural exports from Ukraine to approximately 12 million tons per year, with the underperforming ESL, leads to a simulated decrease in global GDP. The decline in GDP is accompanied by an uptick in domestic prices and the production of agricultural commodities in most regions outside Ukraine. In SII: Strong ESL, the global economic impacts are muted, but still negative. Table 5 shows simulated percentage changes in GDP and changes in welfare measured by Equivalent Variation for SI and SII. For Ukraine, GDP decreases by 10.06% in SI, and by nearly 2% in SII. Welfare in Ukraine is simulated to decrease by $17.6 billion in SI and by $4.5 billion in SII. The GDP and welfare effects in Ukraine are driven by decreases in exports, domestic production, and

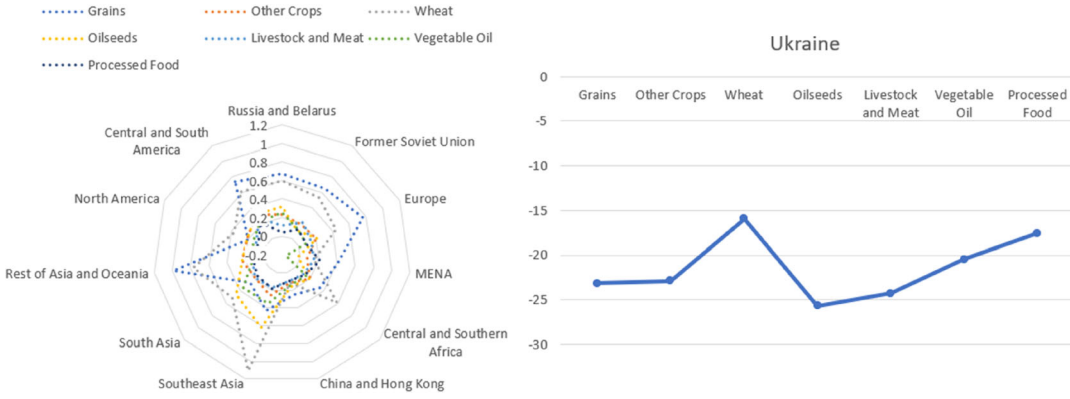

FIGURE 1 Percentage changes in domestic prices across regions and agricultural sectors for Scenario I: Weak European Solidarity Lanes. Changes in prices in Ukraine are considerably greater than in other regions and are indicated separately. *Source*: Authors' presentation using simulation outcomes.

TABLE 5 Percentage changes in Gross Domestic Product (GDP) (%) and welfare changes (million USD) in Scenario I: Weak European Solidarity Lanes and Scenario II: Strong European Solidarity Lanes.

	Scenario I		Scenario II	
Regions	**GDP**	**Welfare**	**GDP**	**Welfare**
Ukraine	−10.06	−17,613.86	−1.99	−4599.08
Russia and Belarus	−0.02	134.50	−0.01	−9.59
Former Soviet Union	−0.08	36.90	−0.04	−51.06
Europe	−0.01	−520.25	0.01	1905.76
Middle East North Africa	−0.07	−1886.69	−0.03	−1095.57
Central and Southern Africa	−0.01	22.00	−0.01	−163.24
China and Hong Kong	−0.01	−798.67	−0.01	−642.52
Southeast Asia	−0.01	193.72	−0.01	77.60
South Asia	−0.03	−707.93	−0.03	−680.40
Rest of Asia and Oceania	0.00	3.39	0.00	−206.57
North America	0.00	349.15	0.00	144.26
Central and South America	0.00	1027.11	0.00	272.29

Source: Authors' presentation using simulations outcomes.

domestic prices. Russia and Belarus, FSU, and MENA have less negative GDP effects in SII, whereas simulated GDP effects are similar for both scenarios for Europe, Central and Southern Asia, China and Hong Kong, Southeast Asia, and South Asia. Welfare effects vary across regions outside Ukraine for both scenarios. Russia and Belarus, FSU, Central and Southern Africa, Southeast Asia, Rest of Asia, and the Americas gain welfare ranging from $3.39 million to nearly $1.03 billion in SI. On the contrary, Europe, MENA, South Asia, as well as China and Hong-Kong have simulated welfare losses ranging from $520 million for Europe to nearly $1.89 billion for MENA in SI. MENA has simulated welfare losses of nearly $1.1 billion in SII and is the most negatively affected region in both scenarios because it is the most dependent on agricultural exports from Ukraine. Interestingly, welfare decreases by $520 million for Europe in SI and increases by $1.9 billion in SII. This is driven by a more efficient allocation of resources in production when the decrease in exports from Ukraine is less severe in SII than in SI. While five out of 12 regions have negative simulated welfare effects in SI and eight regions have simulated negative welfare effects in SII, global welfare is higher under SII. Net global welfare losses are equal to more than $5 billion in SII and nearly $20 billion in SI.

Table A3 provides the percentage point differences between Scenarios I and II for simulated changes in production by sector across regions. Overall, the simulated effects on the global economy are muted in SII because Ukraine can export more relative to SI. SII leads to lower simulated production levels than SI for wheat, grain (mostly corn), oilseeds, and vegetable oils in all regions except Ukraine. In SI, output of livestock, meat, and other crops is lower in most regions compared to SII, except for Ukraine. Results are intuitive because Ukraine's export reductions are larger in SI. Figure A10 illustrates the difference in price changes between the two scenarios. Simulated changes in domestic market prices for agricultural products follow a similar pattern to changes in output. Notably, the price impacts in Ukraine are considerably milder in SII. Domestic market prices for agricultural products in Ukraine are simulated to

decrease by approximately 10 to 20 percentage points less in SII compared to SI. Furthermore, simulated domestic price increases in regions outside Ukraine are generally smaller in SII across most sectors and regions with less than half a percentage point difference in price changes between Scenarios I and II. It is worth noting that price effects are relatively modest across sectors and regions in both scenarios, resulting in relatively minor differences in prices.

Table A4 provides the percentage point differences between SII and SI for simulated changes in aggregate exports by sector across regions. On a global scale, SII yields relatively subdued impacts, primarily due to increased export capacity compared to SI. We find lower export quantities for wheat, oilseeds, and vegetable oils across all modeled regions, except Ukraine, for SII compared to SI. The magnitudes of the changes in exports vary across sectors. For wheat, output is less than 5 percentage points lower in SII than SI for 8 out of 11 regions outside Ukraine, with the largest difference for exports from Europe (−10.5 percentage points). The differences between exports in SII and SI are similar for a given region and range from less than one percentage point to 7.5 percentage points lower in SII than SI. Additionally, grain sector exports, primarily comprising corn, are lower in SII than SI across all regions except for China and Hong Kong, with the largest difference simulated for Europe (−17.5 percentage points). Exports of livestock, meat, and other crops are lower in SI than in SII across most regions excluding Ukraine. Our findings align with intuition, given lower agricultural exports from Ukraine in SI compared to SII.

DISCUSSION

While our work simulates two hypothetical scenarios for varying effectiveness of ESL transport routes without access to the Black Sea, it is important to provide a comparison of our results with observed changes in prices and exports during the short period when the ESL existed in May, June, and July 2022 before the BSGI was in effect (Table 6). We compare results with observed changes in prices and exports for wheat and corn given the importance of both crops globally and in Ukraine.[14] Observed exports from Ukraine were lower for corn (−37.5%) and wheat (−76.1%) from May through July 2022 (early in the war when ESL existed before BSGI) compared to the same three-month period in 2021 (before the war began). We exogenously simulate decreased exports from Ukraine for two scenarios relative to 2021 exports for the grains sector that includes mostly corn (−79.1%, SI; −37.2%, SII) and wheat (−97.6%, SI; −65.7%, SII), which are larger declines in SI but relatively close for SII when compared to changes in observed export flows. Observed domestic prices in Ukraine show noteworthy declines for corn (−55.1%) and wheat (−45.6%) when comparing May through July 2022 to the same three-month period in 2021. Comparatively, results show smaller simulated price declines in Ukraine than were observed for grains (primarily corn) (−23.3%, SI, −8.4% SII) and wheat (−16%, SI; −5.6%, SII).

When considering observed data for world prices and exports from other regions around the world, model simulated results are the same sign but of smaller magnitudes. Model simulated increases in world prices for grains (0.14%, SI; 0.06%, SII) and wheat (0.17%, SI; 0.01, SII) do not reflect the relatively larger observed world prices for corn (13.47%) and wheat (52.74%) for the 3 months when the ESL existed without the BSGI compared to the same period in 2021 before the war. Similarly for aggregate exports, model simulated results are smaller in magnitude than observed data.[15] However, simulated corn exports from Russia and Belarus (20.88%, SI; 15.53%, SII) and wheat exports from North America (7.29%, SI; 5.11%, SII) are very close to observed

TABLE 6 Comparison of percentage changes in exports and prices for observed data and model results for SI: Weak European Solidarity Lanes and SII: Strong European Solidarity Lanes.

Prices	Sector	2022 versus 2021[a]	SI	SII
Ukraine domestic Prices	Corn (Grain)	−55.1%	−23.3%	−8.4%
	Wheat	−45.6%	−16.0%	−5.6%
World prices	Corn (Grain)	13.47%	0.14%	0.06%
	Wheat	52.74%	0.17%	0.01%
Exports				
Ukraine	Corn (Grain)	−37.5%	−76.99%	−35.34%
	Wheat	−76.1%	−94.81%	−30.42%
Russia and Belarus	Corn (Grain)	24.71%	20.88%	15.53%
	Wheat	107.19%	8.05%	4.43%
Former Soviet Union	Corn (Grain)	-	23.26%	14.06%
	Wheat	-	5.65%	−0.82%
Europe	Corn (Grain)	57.78%	15.28%	−2.22%
	Wheat	92.45%	4.23%	−6.29%
Middle East North Africa	Corn (Grain)	117.12%	17.90%	11.83%
	Wheat	51.89%	8.33%	−0.82%
Central and Southern Africa	Corn (Grain)	48.04%	5.75%	4.81%
	Wheat	168.15%	4.40%	2.27%
China and Hong Kong	Corn (Grain)	-	5.33%	7.09%
	Wheat	14.00%	8.28%	4.55%
Southeast Asia	Corn (Grain)	1.83%	5.73%	4.55%
	Wheat	38.64%	11.04%	10.75%
South Asia	Corn (Grain)	32.46%	8.13%	6.02%
	Wheat	137.25%	20.48%	17.05%
Rest of Asia and Oceania	Corn (Grain)	46.93%	14.41%	12.08%
	Wheat	34.74%	10.29%	9.03%
North America	Corn (Grain)	1.84%	5.45%	5.32%
	Wheat	6.38%	7.29%	5.11%
Central and South America	Corn (Grain)	58.22%	12.67%	9.24%
	Wheat	36.13%	4.11%	3.52%

Source: Authors' calculations based on data from MAPF (2023), FRED (2024a), FRED (2024b), and United Nations (2024).
[a]Observed prices and exports are for the three-month period from May through July 2022 when the ESL existed, but the BSGI was not yet in effect, compared to the same three-month period from May through July 2021 before the war. Observed data includes monthly observations for corn and wheat. SI and SII are authors' simulated results for grains (mostly corn) and wheat from the economywide model.

export changes for corn from Russia and Belarus (24.7%) and wheat from North America (6.38%).

While there are noteworthy differences between the assumptions of our model simulations and the reality of the three-month pre-BSGI window of the ESL, which make comparison a

challenge, we highlight that we simulate changes in agricultural exports from Ukraine that are larger for SI than was observed; yet are very close to observed data for the pre-BSGI ESL period for SII. Model results for changes in domestic prices in Ukraine, world prices, and exports from regions outside Ukraine are generally lower in both scenarios than observed when comparing the 2022 pre-BSGI ESL period with the same time frame in 2021 before the war began.

For additional context, we provide data on Ukraine's agricultural production and exports before and after the war in Table 7. Annual agricultural production is lower for all sectors in 2022 and 2023 than 2021 prewar levels. The largest drop in production in 2022 compared to 2021 was observed for grains and wheat, which decreased by −38.3% and −35.5%, respectively. Moderate declines were observed for other crops (−15.2%) and oilseeds (−20.7%) during the first year of the war. While livestock and meat production had the smallest production decline in 2022 compared to 2021 (−12.2%), this was the only sector that did not grow in 2023 compared to 2022, showing a further decrease of −3%. The decline in agricultural exports from Ukraine observed after the invasion and before the launch of BSGI (March–July 2022) is noteworthy. The most substantial drop occurred for vegetable oil, which was in tandem with a sudden increase in oilseed exports as described previously. Changes in export quantities were relatively minor across all groups when the ESL began but the BSGI was not yet in place (May–July 2022). Export flows recovered after the BSGI went into effect, and export volumes of grains, other crops, and livestock and meat returned to relatively similar levels as were observed before the start of the invasion.

Furthermore, it is important to investigate observed effects on exports from countries outside Ukraine before and after the BSGI was operational. While our simulations model trade diversion through increased exports from regions outside Ukraine to replace lost exports during

TABLE 7 Ukraine's production and exports before and during the war, million metric tons.

	Production			Exports			
	2021	2022	2023	Before invasion (May 21–February 22)	After invasion (March–April 22)	ESL (May–July 22)	ESL and BSGI (August 22–July 23)
Grains	53.09	32.77	37.65	29.40	1.89	3.61	32.40
Other crops	17.61	14.94	18.72	0.06	0.01	0.01	0.04
Wheat	32.15	20.73	21.63	19.63	0.43	0.57	17.36
Oilseeds	22.82	18.09	21.69	1.04	0.22	1.54	5.24
Livestock and meat	11.14	9.78	9.48	0.42	0.04	0.13	0.46
Vegetable oil	-	-	-	4.79	0.30	0.80	5.96

Note: Reported export data includes goods registered for export operations and listed in the customs registry. This does not necessarily indicate that the physical export of these goods occurred immediately. Grains include corn, barley, rye, oats, buckwheat, and millet. Other crops include sugar beets, cabbage, tomatoes, onions, apples, and grapes. Oilseeds include soybeans, winter rapeseed and colza (spring rapeseed), and sunflower seeds. Livestock and meat include beef, pork, poultry of all species, and cow milk. Vegetable oil includes sunflower seed oil, rapeseed oil, and soybean oil. Data on vegetable oil production is not available.

Source: Authors' calculations based on State Statistics of Ukraine (2024) and State Customs of Ukraine (2024) data.

the war when Ukraine's exports were stifled, the data reveals substantial variations in wheat and corn exports from various countries during the periods of March through July 2022 and then August 2022 through July 2023, spanning the onset of the invasion before BSGI and its aftermath. Given the volatility of exports to African nations with heightened food insecurity levels and other global market forces, understanding the changes in exported quantities attributed to the Ukrainian conflict proves to be exceptionally challenging. To address this, we focus on analyzing overall observed changes in export volumes of wheat and corn by originating country before and after the BSGI was implemented compared to the average of equivalent periods in 2021 and 2020.

The notable beneficiaries in terms of increased wheat export quantities from March through July 2022 (the start of the war before BSGI) are India, Brazil, Turkey, and Argentina.[16] The United States and France capitalized on the surge in global market prices for wheat, significantly boosting their export revenues. Following implementation of the BSGI, exports from India and Argentina regressed to prewar levels, while exports from Turkey and Brazil remained relatively high. Turkey's sustained prominence as a wheat exporter can be partly attributed to its involvement in BSGI negotiations and its role as a transit hub for Ukrainian grains. The United States and Argentina maintained their positions as leading global corn exporters, capitalizing on heightened prices. Meanwhile, Brazil and France also saw increases in both corn prices and quantities exported after the start of the war. The largest increases for corn exporters during the pre-BSGI war period when compared to the average of equivalent periods in 2021 and 2020 were for Poland, Brazil, Canada, Romania, France, South Africa, and India[17] (International Trade Centre, 2024).

From March through July 2022, grain exports from many European countries with seaport logistics or transit also exhibited substantial growth, ranging from 20% to 271% for wheat,[18] and more than 10% for corn throughout Europe,[19] depending on the country. The surge in exports from Europe was largely attributed to re-exportation, given that Ukrainian grains were rerouted through its western borders. During the BSGI, Latvia, Romania, Serbia, the United Kingdom, Italy, Greece, Portugal, and Slovenia maintained their strengthened positions as wheat exporters. During the BSGI period from August 2022 through July 2023, Poland increased wheat exports by 47%, Slovakia by 18%, and Croatia by 11%, largely due to the continued flow of Ukrainian wheat through their respective channels. Similarly, Poland, Slovakia, Portugal, Spain, the United Kingdom, Latvia, Italy, Sweden, and Finland maintained strengthened corn export positions through implementation of the BSGI (International Trade Centre, 2024). There were also notable increases for relatively small corn exporters in Africa[20] and the Americas.[21] Corn exports increased by at least 15% from across Asia and the South Pacific[22] with improved export positions maintained by several countries[23] through the BSGI period, in tandem with increased corn exports for some countries in the region[24] after BSGI implementation.

CONCLUSIONS

Prior to the Russian invasion of Ukraine, global agricultural markets were grappling with elevated prices and constrained supplies due to disruptions from the COVID-19 pandemic and other market forces, such as reduced global supplies caused by drought. Agricultural output prices and input prices increased exponentially since 2020, and war-induced impacts on supply chains further exacerbated price pressure (Baffes & Temaj, 2022). Tight stocks and supply shocks trigger higher prices and amplify market volatility that puts pressure on global

agricultural markets and food security, especially in developing countries. While there is a growing literature on the effects of the war in Ukraine, this work provides an important and timely contribution with respect to simulated scenarios for agricultural export declines from Ukraine.

This study simulates the repercussions of reduced agricultural exports from Ukraine due to the war by employing two distinct scenarios: one with weak ESL, assuming Russian attacks on ESL infrastructure, and another with strong ESL assuming no Russian attacks on ESL. The ESL Program, initiated by the EU in May 2022, was designed to create alternative transport routes for Ukrainian exports via rail, road, and inland waterways to bolster the Ukrainian economy during the ongoing war and contribute to ensuring global food security. By June 2023, 44.4 million tons of grain, oilseeds, and related products were exported from Ukraine through the ESL. Trade through the ESL accounted for approximately 60% of Ukraine's grain exports, while the remaining 40% was exported through the sea shipment corridor under the Turkey and UN moderated Black Sea Grain Initiative. The ESL also enabled exports of approximately 36 million tons (33 billion euros) of nonagricultural products. The success of the ESL Program has been severely threatened since Russia began attacking Ukraine's Danube River ports (at Izmail and Reni) and other ESL infrastructure after the dissolution of the BSGI in July 2023. This situation challenges Ukraine's capacity to export agricultural goods, thereby endangering its domestic economy and having adverse consequences for import-dependent nations facing food insecurity. Consequently, it is imperative to understand the far-reaching implications of the effective operation of the ESL for Ukraine and global economies alike.

GDP and welfare effects of war-induced decreases in agricultural exports from Ukraine are simulated for two scenarios. In both scenarios, agricultural production, domestic prices, and exports increase in most regions, except Ukraine. GDP and welfare effects are negative or non-positive across regions, and the Middle East and North Africa are the most negatively affected. This indicates that the ESL cannot compensate for missing agricultural exports from Ukraine without access to the relatively cheaper Black Sea routes employed before the war.

There are several primary policy implications from this work. To begin, potential changes in bilateral trade routes underscore the importance of efficient transportation through the ESL as an alternative to conventional Black Sea routes when circumstances require it. This also highlights opportunities to expand trade with partners and informs future trade policy with respect to diversification of export routes during and postwar. As the ESL helps mitigate the adverse effects of the war, the critical role of well-functioning transportation infrastructure becomes apparent. In the postwar era, the full-scale operation of the ESL has the potential to boost trade between Ukraine and the EU, while also fostering the prospects for Ukraine's potential accession to the EU. On the other hand, investing in the ESL could act as an insurance policy for Ukraine during the war, making the country less vulnerable to potential interruptions of the Black Sea route. This could prove extremely valuable if the war with Russia develops into a protracted, frozen conflict with constant threats to the openness and safety of maritime traffic, which appears to be the case currently after 2 years of the war and unclear expectations with respect to its end. While Ukraine has been exporting even more grains and other products after the dissolution of the BSGI, continued potential to export through the Black Sea remains uncertain as shipments are continually under the threat of Russia's military interests on the Black Sea as the war continues. The Black Sea Basin (the Azov Sea and the Black Sea) and the Crimean Peninsula in particular, which was annexed by Russia in 2014, is very important to Russia's export revenues and its military and regional power demonstration and projection. Approximately 20%–30% of Russia's monthly seaborne crude oil and oil product exports, about 8% of

total liquified petroleum gas exports, as well as all its grain exports have been shipped via the Black Sea Basin (Dodonov et al., 2024). Also, most of Russia's exports of ammonia were shipped by pipeline through Ukraine's Black Sea port Pivdennyi, but the pipeline has not been in operation since February 2022 (Glauber et al., 2023). From a military perspective, the Black Sea and annexed Crimea are important for Russia to weaken Ukraine's export capacity by simply threatening the shipping routes from Ukraine's major ports, and the Kerch Bridge that joins Russia with the Crimean Peninsula has been one of the two supply routes for Russian forces in southern Ukraine (Mappes et al., 2023). After occupation, Crimea was highly militarized and transformed into a modern military and nuclear base (ESD, 2020) and the Black Sea overall is considered as Russia's springboard for the projection of power and influence in the Mediterranean, the Middle East, North Africa, and southern Europe (Meister, 2022). This waterway is of strategic importance for both Ukraine and Russia when considering the importance of exports for Ukraine's economy, and the critical nature of the Black Sea to transport exports. Understanding changes in prices and production across regions in response to decreased exports from Ukraine informs how market conditions may change in response to continued war under varying capacity assumptions for alternative transport from Ukraine through Europe. Finally, the simulated GDP and welfare effects resulting from war-related agricultural export shocks shed light on the magnitude of potential war-induced gains and losses across regions. It is also important to note the limitations of this research and identify opportunities for future investigation. As described in our discussion, there are important changes in export flows that have evolved throughout the war that we are unable to capture in an annual model. Furthermore, while we simulate decreased exports from Ukraine that provide model-simulated changes in domestic production, it would be informative to directly investigate production impacts in Ukraine. Future work could employ a modeling framework with detailed land-use specifications to simulate the war-related disruptions in agricultural production in Ukraine to determine the impacts of decreased agricultural land productivity in war-stricken areas. Moreover, there are a myriad of trade policy interventions that have arisen during the war including Western sanctions on Russia and export restrictions imposed by many agricultural exporters given food security concerns. While there is a growing literature on the effects of war-related policy effects, more research is needed to understand the complex trade policy landscape that has emerged over the course of the war. Further insight into the global, economywide effects of the war in Ukraine is warranted and relevant for policymakers around the world.

ACKNOWLEDGMENTS

The authors would like to thank Taís de Menezes and Erwin Corong for their research support. This work was also supported by the International Agricultural Trade Research Consortium, the USDA National Institute of Food and Agriculture, Hatch project COL00232A, accession 7006333, and the U.S. Agency for International Development.

ENDNOTES

[1] Egypt received the largest share at 19% of Ukrainian wheat exports, followed by Tunisia (5%), Libya (4%), Algeria and Ethiopia (2% each), and 1% each for Sudan, Yemen, Djibouti, Kenya, Mauritania, and Nigeria.

[2] In Egypt and Tunisia, where 28.5% of the population experienced moderate to severe food insecurity, Ukrainian wheat comprised 18.5% and 26.0% of the total domestic wheat supply, respectively (Abay et al., 2023a). Kenya and Mauritania, where 72.3% and 53.7% of the population faced food insecurity, respectively, with Ukrainian wheat comprising 10.0 and 26.3% of domestic wheat supplies, respectively (Food and Agriculture Organization of the United Nations, 2024a; ITC, 2024).

[3] Black Sea milling wheat prices returned to 229.77 USD/mt in June 2023.

[4] Approximately 80% of the United Nations World Food Program purchases of wheat from Ukraine, which were 50% higher than in 2021 and 2022, were sourced transported through the BSGI as of July 2023 when the agreement was terminated (United Nations, 2023).

[5] In 2021, oilseeds, nuts and derived products provided 6.2% of total global calorie intake and 51.5% of all calories from fat (FAO, 2024a; Jagtap et al., 2022). Sunflower oil consumption provides about 31.4 kilocalories (kcal) per day (d), equal to 1.23% of the daily food balance in India, and contributes 7.93 kcal/d, 0.23% of the daily food balance in China (FAO, 2023; Ritchie, 2022).

[6] Similarly, wheat and wheat products provide 32.8% of daily consumption in Turkey where 18% of wheat imports come from Ukraine in 2021. In Iran, 3% of imports are sourced from Ukraine in 2021 and 38.6% of domestic consumption relies on wheat and wheat products (FAO, 2023; International Trade Centre, 2021).

[7] The five most negatively affected sectors are residential buildings ($55.9 billion), logistics infrastructure including, roads, railways, ports and aviation ($36.6 billion), industrial assets ($11.4 billion), education ($9.7 billion), energy ($8.8 billion), and agriculture ($8.7 billion) (Neyter et al., 2022).

[8] The three most damaged asset groups are machinery ($4.62 billion), stored commodities ($2 billion), and storage facilities ($1.3 billion).

[9] The cost to clear the land from hazardous material is currently estimated between $12.8 and $26.6 billion (Nivievskyi & Neyter, 2024).

[10] For example, Black Sea Free on Board (FOB) prices for urea outside Ukraine ranged from $370 to $385 per ton, while the price for urea at customs clearance in Ukraine reached $750 per ton (Derzhzovnishinform, 2023; Ukrainian Agribusiness Club, 2022).

[11] This includes a 50% decrease in other oil exports (HS 1510), a 16% decrease in sunflower seed oil exports (HS 1512), a 60% decrease in rapeseed oil exports (HS 1514).

[12] Beginning stocks for vegetable oil dropped by 72% (93 thousand tons) and ending stocks dropped by 52% (44 thousand tons) in fall 2022 compared to fall 2021 (USDA, 2023).

[13] The extrapolation considers the maximum that could be exported from March through May 2022, which included stocks from the previous harvest, but was well below stocks available for export. Monthly average exports of agricultural products from Ukraine fluctuated between 5 and 6 million tons prior to the full-scale invasion. Since the beginning of the full-scale invasion, Ukraine's production dropped by 15%–20% on average due to the war. Accordingly, the drop in production does not exceed annualized exports from March through May 2022, considering stored stocks from the previous seasons and decreased domestic consumption.

[14] In 2023, Ukraine exported $21.9 billion in agricultural products, of which, wheat comprised 13% of the total ($2.9 billion) and corn represented 23% of the total ($4 billion). We explicitly model wheat and corn are included in the grains sector in this analysis. Corn represents approximately 80% of Ukraine's grain crop production (excluding wheat) and is appropriate for comparison (MAPF, 2023).

[15] Model simulated changes in aggregate exports for grains (mostly corn) and wheat from regions outside Ukraine are smaller than observed data in all cases except corn exports from North America and Southeast Asia.

[16] Wheat exports increased from March through July 2022 compared to the average of equivalent periods in 2021 and 2020 for Brazil (from 0.06 to 1.1 mmt), India (340%, from 1 to 4.4 mmt), Turkey (250%, from 0.04 to 0.14 mmt), and Argentina (38%, from 4.5 to 3.2 mmt).

[17] Corn exports increased from Poland (200%, from 0.6 to 1.8 mmt), Brazil (86%, from 3.7 to 6.9 mmt), Canada (71%, from 0.7 to 1.2 mmt), Romania (43%, from 2.1 to 3 mmt), France (42%, from 1.9 to 2.7 mmt), South Africa (33%, from 1.5 to 2 mmt), and India (40%, from 1 to 1.4 mmt).

[18] Substantial wheat export increases from March through July 2022 compared to average of the equivalent period in 2021 and 2020 are observed for Portugal, Bosnia and Herzegovina, Slovenia, Serbia, Italy, the United Kingdom, the Netherlands, Romania, Estonia, Bulgaria, Cyprus, Greece, and Latvia.

[19] Corn exports increased by at least 10% from Romania, Poland, Croatia, Slovakia, Austria, Portugal, Spain, the United Kingdom, Czech Republic, Latvia, Italy, Sweden, Germany, Switzerland, Bosnia and Herzegovina, and Finland.

[20] In Africa, corn exports increases ranged from 35% to more than 300% depending on the country (including South Africa, Zambia, Angola, Malawi, Mali, Senegal, and Mozambique) during the non-BSGI period (March through July 2022) and remained elevated during the BSGI period for South Africa, Zambia, Angola, and Benin, though these represent very small export flows in absolute terms.

[21] There were increased corn exports from March 2022 to July 2023 for Paraguay (204%, from 0.3 to 0.8 mmt), Nicaragua (from 259 to 4800 mt), and Guatemala (75%, from 589 to 1000 mt).

[22] Corn exports increased by at least 15% from Australia, Thailand, Turkey, Georgia, Malaysia, State of Palestine, Philippines, Pakistan, Chinese Taipei, Republic of Korea, and India.

[23] Increased exports were maintained through BSGI for India, Turkey, Georgia, Palestine, and Chinese Taipei.

[24] Slovenia, Greece, Cambodia, Indonesia, Estonia, and Bahrain increased corn exports during the BSGI period.

REFERENCES

Abay, Kibrom, Lina Abdelfattah, Clemens Breisinger, Joseph Glauber, and David Laborde. 2023a. "The Russia-Ukraine Crisis Poses a Serious Food Security Threat for Egypt." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_24.

Abay, Kibrom, Clemens Breisinger, Joseph Glauber, Sikandra Kurdi, David Laborde, and Khalid Siddig. 2023b. "The Russia-Ukraine War: Implications for Global and Regional Food Security and Potential Policy Responses." *Global Food Security* 36: 100675. https://doi.org/10.1016/j.gfs.2023.100675.

Adjemian, Michael K., Shawn Arita, Seth Meyer, and Delmy Salin. 2024. "Factors Affecting Recent Food Price Inflation in the United States." *Applied Economic Perspectives and Policy* 46(1): 648–676. https://doi.org/10.1002/aepp.13378.

Aguiar, Angel, Maksym Chepeliev, Erwin Corong, and Dominique van der Mensbrugghe. 2022. "The GTAP Data Base: Version 11." *Journal of Global Economic Analysis* 7(2): 1–37. https://doi.org/10.21642/JGEA.070201AF.

Ajeigbe, Kola B. 2023. "Does the Russia-Ukraine War Affects Trade Relations and Foreign Direct Investment Flows from Europe into Asia and Africa?" *International Journal of Research in Business and Social Science* 12(2): 287–300. https://doi.org/10.20525/ijrbs.v12i2.2403.

Alam, Md., Mosab I. Kausar, Mabruk Billah Tabash, Sanjeev Kumar, and Suhaib Anagreh. 2022. "The Impacts of the Russia–Ukraine Invasion on Global Markets and Commodities: A Dynamic Connectedness among G7 and BRIC Markets." *Journal of Risk and Financial Management* 15(8): 352. https://doi.org/10.3390/jrfm15080352.

Aliu, Florin, Jiří Kučera, and Simona Hašková. 2023. "Agricultural Commodities in the Context of the Russia-Ukraine War: Evidence from Corn, Wheat, Barley, and Sunflower Oil." *Forecast* 5(1): 351–373. https://doi.org/10.3390/forecast5010019.

Armington, Paul S. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *Staff Papers (International Monetary Fund)* 16(1): 159–178. https://doi.org/10.2307/3866403.

Arndt, Channing, Xinshen Diao, Paul Dorosh, Karl Pauw, and James Thurlow. 2023. "The Ukraine War and Rising Commodity Prices: Implications for Developing Countries." *Global Food Security* 36: 100680. https://doi.org/10.1016/j.gfs.2023.100680.

Babar, Maria, Habib Ahmad, and Imran Yousaf. 2023. "Returns and Volatility Spillover Between Agricultural Commodities and Emerging Stock Markets: New Evidence from COVID-19 and Russian-Ukrainian War." *International Journal of Emerging Markets*. ahead-of-print. https://doi.org/10.1108/IJOEM-02-2022-0226.

Baffes, John, and Kaltrina Temaj. 2022. "Food Prices Continued their Two-Year-Long Upward Trajectory." World Bank Blogs. https://blogs.worldbank.org/opendata/food-prices-continued-their-two-year-long-upward-trajectory.

Balana, Bedru, Kwaw Andam, Mulubrhan Amare, Dolapo Adeyanju, and David Laborde. 2023. "The Russia-Ukraine Crisis Presents Threats to Nigeria's Food Security, but Potential Opportunities for the

Fertilizer, Energy Sectors." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_32.

Beckman, Jayson, and Amanda M. Countryman. 2021. "The Importance of Agriculture in the Economy: Impacts from COVID-19." *American Journal of Agricultural Economics* 103(5): 1595–1611. https://doi.org/10.1111/ajae.12212.

Beckman, Jayson, and Maros Ivanic. 2023. "Decomposing a Year of Uncertainty in Agricultural Markets." *Choices* 38(2): 44–51. https://www.choicesmagazine.org/choices-magazine/theme-articles/turmoil-in-global-food-agricultural-and–input-markets-implications-of-russias-invasion-of-ukraine/decomposing-a-year-of-uncertainty-in-agricultural-markets.

Beraich, Mohamed Karim, Jaouard Laamire Amzile, Omar Zirari, and Mohamed A. Fadali. 2022. "Volatility Spillover Effects of the US, European and Chinese Financial Markets in the Context of the Russia–Ukraine Conflict." *International Journal of Financial Studies* 10(4): 95. https://doi.org/10.3390/ijfs10040095.

Boubaker, Sabri, John Goodell, K. P. Dharen, and Vineeta Kumari. 2022. "Heterogeneous Impacts of Wars on Global Equity Markets: Evidence from the Invasion of Ukraine." *Finance Research Letters* 48(3): 102934. https://doi.org/10.1016/j.frl.2022.102934.

Bougias, Alexandros, Athanasios Episcopos, and George N. Leledakis. 2022. "Valuation of European Firms during the Russia-Ukraine War." *Economics Letters* 218(C): 110750. https://doi.org/10.1016/j.econlet.2022.110750.

Boulanger, Pierre, Hasan Dudu, Emanuele Ferrari, and George Philippidis. 2016. "Russian Roulette at the Trade Table: A Specific Factors CGE Analysis of an Agri-Food Import Ban." *Journal of Agricultural Economics* 67(2): 272–291. https://doi.org/10.1111/1477-9552.12156.

Boungou, W., and A. Yatié. 2022. "The Impact of the Ukraine–Russia war on World Stock Market Returns." *Economics Letters* 215: 110516. https://doi.org/10.1016/j.econlet.2022.110516.

Breisinger, Clemens, Xinshen Diao, Paul A. Dorosh, Juneweenex Mbuthia, Lensa Omune, Edwin O. Oseko, Angga Pradesha, and James Thurlow. 2023b. "Rising Commodities Prices Driven by the Russia-Ukraine Crisis Threaten to Undermine Kenya's Economy, Increase Poverty." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_33.

Breisinger, Clemens, Nadim Khouri, Joseph Glauber, and David Laborde. 2023c. "One of the world's Worst Economic Collapses, Now Compounded by the Ukraine Crisis: What's Next for Lebanon?" In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_26.

Breisinger, Clemens, Oliver Kirui, Paul A. Dorosh, Joseph W. Glauber, and David Laborde. 2023a. "The Russia-Ukraine Conflict Is Likely to Compound Sudan's Existing Food Security Problems." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_30.

Bullock, David W., Prithviraj Lakkakula, and William W. Wilson. 2023. "Russia-Ukraine Conflict and the Global Food Grain Price Analysis." *Choices* 38(2): 35–43. https://www.choicesmagazine.org/choices-magazine/theme-articles/turmoil-in-global-food-agricultural-and–input-markets-implications-of-russias-invasion-of-ukraine/russia-ukraine-conflict-and-the-global-food-grain–price-analysis.

Chepeliev, Maksym, Maryla Maliszewska, and Maria S. E. Pereira. 2022. "Effects on Trade and Income of Developing Countries." In *The Impact of the War in Ukraine on Global Trade and Investment*, edited by M. Ruta. Washington, DC: World Bank.

Chowdhury, Tahreen T., Paul A. Dorosh, Rizwana Islam, and Angga Pradesha. 2023. *Impacts of the Russia-Ukraine War Price Shocks on the Bangladesh Economy: A General Equilibrium Analysis*. IFPRI Discussion Paper 2182. Washington, DC: International Food Policy Research Institute.

Colgan, Jeff D., Alexander S. Gard-Murray, and Miriam Hinthorn. 2023. "Quantifying the Value of Energy Security: How Russia's Invasion of Ukraine Exploded Europe's Fossil Fuel Costs." *Energy Research & Social Science* 103(11): 103201. https://doi.org/10.1016/j.erss.2023.103201.

Corong, Erwin L., Thomas W. Hertel, Robert McDougall, Marinos E. Tsigas, and Dominique van der Mensbrugghe. 2017. "The Standard GTAP Model, Version 7." *Journal of Global Economic Analysis* 2(1): 1–119. https://doi.org/10.21642/JGEA.020101AF.

Derzhzovnishinform. 2023. "World Prices for Fertilizers Are Falling Rapidly, but Not in Ukraine." DZI. https://dzi.gov.ua/press-centre/news/svitovi-tsiny-na-dobryva-strimko-padayut-ale-ne-v-ukrayini/.

Diffenbaugh, Noah S., Thomas W. Hertel, Martin Scherer, and Monika Verma. 2012. "Response of Corn Markets to Climate Volatility under Alternative Energy Futures." *Nature Climate Change* 2: 514–18. https://doi.org/10.1038/nclimate1491.

Dodonov, Borys, Benjamin Hilgenstock, Anatoliy Kravtsev, Yuliia Pavytska, and Nataliia Shapoval. 2024. "Russian Oil Tracker." KSE Institute. https://kse.ua/wp-content/uploads/2024/03/ROT_FEB24.pdf.

Elleby, Christian, Dominguez Ignacio P, Giampiero Genovese, Wyatt Thompson, Marcel Adenauer, and Hubertus Gay. 2023. "A Perfect or Persistent Storm for Global Agricultural Markets: High Energy Prices and the Russia-Ukraine War." *Choices* 38(2): 13–18. https://www.choicesmagazine.org/choices-magazine/theme-articles/turmoil-in-global-food-agricultural-and–input-markets-implications-of-russias-invasion-of-ukraine/a-perfect-or-persistent-storm-for-global-agricultural-markets-high-energy-prices-and-the-russia-ukraine-war.

ESD. European Security and Defense. 2020. "How Much Has Russia Militarised the Crimea?" https://euro-sd.com/2020/03/allgemein/16510/how-much-has-russia-militarised-the-crimea/.

EU Commission. 2022b. "The Impact of Russia's War against Ukraine on Global Food Security." May 2022. The European Commission's Knowledge Centre for Global Food and Nutrition Security. https://knowledge4policy.ec.europa.eu/publication/impact-russia%E2%80%99s-war-against-ukraine-global-food-security-%E2%80%93-kc-fns-review-may-2022a_en.

EU Commission. 2022c. "Commission Decision of 12.5.2022 on the Signing of a High-Level Understanding between the European Union and Ukraine on Indicative Maps of the Trans-European Transport Network in Ukraine, Being a High-Level Agreement within the Meaning of Article 49(6) of Regulation (EU) No 1315/2013 (TEN-T regulation)." https://transport.ec.europa.eu/system/files/2022b-05/C_2022_3204.pdf.

EU Commission. 2023a. "DG near Press-Release. Following the Expiry of the Restrictive Measures on Ukrainian Exports of Grain, Ukraine Agrees to Introduce Measures to Avoid a Renewed Surge in EU Imports." https://neighbourhood-enlargement.ec.europa.eu/news/following-expiry-restrictive-measures-ukrainian-exports-grain-ukraine-agrees-introduce-measures-2023-09-15_en.

EU Commission. 2023b. "Factsheet on EU-Ukraine Solidarity Lanes Joint Coordination Platform." https://ec.europa.eu/commission/presscorner/detail/en/FS_23_4322

EU Commission. 2024. "EU-Ukraine Deep and Comprehensive Free Trade Area." https://trade.ec.europa.eu/access-to-markets/en/content/eu-ukraine-deep-and-comprehensive-free-trade-area.

FAO. Food and Agriculture Organization of the United Nations. 2023. "Food Balance Sheets 2010–2021: Global, Regional and Country Trends." FAOSTAT Analytical Brief 72, Rome. https://doi.org/10.4060/cc8088en.

FAO. Food and Agriculture Organization of the United Nations. 2024a. "Food and Agriculture Data." https://www.fao.org/faostat/en/.

FAO. Food and Agriculture Organization of the United Nations. 2024b. "Food Price Monitoring and Analysis Tool." https://fpma.fao.org/giews/fpmat4/#/dashboard/tool/international.

Feng, Fan, Ningyuan Jia, and Faqin Lin. 2023. "Quantifying the impact of Russia–Ukraine crisis on food security and trade pattern: evidence from a structural general equilibrium trade model." *China Agricultural Economic Review* 15(2): 241–258. https://doi.org/10.1108/CAER-07-2022-0156.

FRED. 2024a. "Global Price of Corn." St. Louis FED. https://fred.stlouisfed.org/series/PMAIZMTUSDM.

FRED. 2024b. "Global Price of Wheat." St. Louis FED. https://fred.stlouisfed.org/series/PWHEAMTUSDM.

Glauber, Joseph W. 2023. "Assessing Tight Global Wheat Stocks and their Role in Price Volatility." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_10.

Glauber, Joseph W.. 2024. "Ukraine and Global Agricultural Markets Two Years Later." https://www.ifpri.org/blog/ukraine-and-global-agricultural-markets-two-years-later.

Glauber, Joseph W., Brian McNamara, and Elsa Oliveti. 2023. "Increased Tensions in Ukraine Again Threaten the Black Sea Grain Initiative." https://www.ifpri.org/blog/increased-tensions-ukraine-again-threaten-black-sea-grain-initiative.

Goyal, Raghav, and Sandro Steinbach. 2023. "Agricultural Commodity Markets in the Wake of the Black Sea Grain Initiative." *Economics Letters* 231: 111297. https://doi.org/10.1016/j.econlet.2023.111297.

Grant, Jason, Shawn Arita, Chaoping Xie, and Sharon Sydow. 2023. "Russia's Invasion of Ukraine: The war's Initial Impacts on Agricultural Trade." *Choices* 38(2): 52–64. https://www.choicesmagazine.org/choices-magazine/theme-articles/turmoil-in-global-food-agricultural-and–input-markets-implications-of-russias-invasion-of-ukraine/russias-invasion-of-ukraine-the-wars-initial-impacts-on-agricultural-trade.

He, Xi, Miguel Carriquiry, Amani Elobeid, Dermot Hayes, and Wendong Zhang. 2023. "Impacts of the Russian-Ukraine Conflict on Global Agriculture Commodity Prices, Trade, and Cropland Reallocation." *Choices* 38(2): 19–26. https://www.choicesmagazine.org/choices-magazine/theme-articles/turmoil-in-global-food-agricultural-and–input-markets-implications-of-russias-invasion-of-ukraine/impacts-of-the-russian-ukraine-conflict-on-global-agriculture-commodity-prices-trade-and-cropland-reallocation.

Hebebrand, Charlotte, and Joseph Glauber. 2023. "The Russia-Ukraine War after a Year: Impacts on Fertilizer Production, Prices, and Trade Flows." https://www.ifpri.org/blog/russia-ukraine-war-after-year-impacts-fertilizer-production-prices-and-trade-flows.

Hertel, Thomas W., Wallace E. Tyner, and Dileep K. Birur. 2010. "The Global Impacts of Biofuel Mandates." *The Energy Journal* 31(1): 75–100. http://www.jstor.org/stable/41323271.

Ihle, Rico, Ziv Bar-Nahum, Oleg Nivievskyi, and Ofir D. Rubin. 2022. "Russia's Invasion of Ukraine Increased the Synchronization of Global Commodity Prices." *Australian Journal of Agricultural and Resource Economics* 66(4): 775–796. https://doi.org/10.1111/1467-8489.12496.

IndexMundi. 2023. "Sunflowerseed Oil Domestic Consumption by Country in 1000 MT." https://www.indexmundi.com/agriculture/?commodity=sunflowerseed-oil&graph=domestic-consumption.

IPES-FOOD. International Panel of Experts on Sustainable Food Systems. 2022. "Another Perfect Storm? How the Failure to Reform Food Systems Has Allowed the War in Ukraine to Spark a Third Global Food Price Crisis in 15 Years, and What Can be Done to Prevent the Next One." A Special Report by IPES-Food, May 2022. https://ipes-food.org/_img/upload/files/AnotherPerfectStorm.pdf.

ITC. International Trade Centre. 2024. "Trade Map – Trade Statistics for International Business Development." https://www.trademap.org/Index.aspx.

Izzeldin, Marwan, Yaz G. Muradoğlu, Vasileios Pappas, Athina Petropoulou, and Sheeja Sivaprasad. 2023. "The Impact of the Russian-Ukrainian War on Global Financial Markets." *International Review of Financial Analysis* 87: 102598. https://doi.org/10.1016/j.irfa.2023.102598.

Jagtap, Sandeep, Hana Trollman, Frank Trollman, Guillermo García-García, Carlo Parra-López, Linh Duong, Wayne Martindale, et al. 2022. "The Russia-Ukraine Conflict: Its Implications for the Global Food Supply Chains." *Food* 11(14): 2098. https://doi.org/10.3390/foods11142098.

Karkowska, Renata, and Szczepan Urjasz. 2023. "How Does the Russian-Ukrainian War Change Connectedness and Hedging Opportunities? Comparison Between Dirty and Clean Energy Markets Versus Global Stock Indices." *Journal of International Financial Markets, Institutions and Money* 85: 101768. https://doi.org/10.1016/j.intfin.2023.101768.

Kurdi, Sikandra, Clemens Breisinger, Joseph W. Glauber, and David Laborde. 2023. "The Russian Invasion of Ukraine Threatens to Further Exacerbate the Food Insecurity Emergency in Yemen." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_27.

Laber, Moritz, Peter Klimek, Martin Bruckner, Liuhuaying Yang, and Stefan Thurner. 2023. "Shock Propagation from the Russia–Ukraine Conflict on International Multilayer Food Production Network Determines Global Food Availability." *Nature Food* 4: 508–517. https://doi.org/10.1038/s43016-023-00771-4.

Legrand, Nicolas. 2022. "War in Ukraine: The Rational "Wait-and-See" Mode of Global Food Markets." *Applied Economic Perspectives and Policy* 45(2): 626–644. https://doi.org/10.1002/aepp.13335.

Liadze, Iana, Corrado Macchiarelli, Paul Mortimer-Lee, and Patricia S. Juanino. 2022. "Economic Costs of the Russia-Ukraine War." *The World Economy* 46(4): 874–886. https://doi.org/10.1111/twec.13336.

Mamun, Al, and M. H. M. Imrul Kabir. 2023. "The Remittance, Foreign Direct Investment, Export, and Economic Growth in Bangladesh: A Time Series Analysis." *Arab Economic and Business Journal* 15(1): 30–46. https://doi.org/10.38039/2214-4625.1022.

MAPF. Ministry of Agrarian Policy and Food of Ukraine. 2023. "Field Online: Rapid Sowing and Harvesting Campaign Assessment." https://minagro.gov.ua/map.

Mappes, Grace, Karolina Hird, Nicole Wolkov, Christina Harward, and Frederick W. Kagan. 2023. "Russian Offensive Campaign Assessment, July 17, 2023." Institute for the Study of War. https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-july-17-2023.

Martin, Will, and Nicholas Minot. 2023. "The Impact of Price Insulation on World Wheat Markets during COVID-19 and the Ukraine Crisis." IFRI Discussion Paper 02175. https://doi.org/10.2499/p15738coll2.136616.

Martyshev, Pavlo, Oleg Nivievskyi, and Mariia Bogonos. 2023. "Regional War, Global Consequences: Mounting Damages to Ukraine's Agriculture and Growing Challenges for Global Food Security." In *The Russia-Ukraine Conflict and Global Food Security*, edited by J. Graubler and D. Laborde Debucquet. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294394_23.

Meister, Stefan. 2022. "Geopolitical Shifts in the Black Sea Region." Internationale Politik Quarterly, December 06, 2022. https://ip-quarterly.com/en/geopolitical-shifts-black-sea-region.

Meredith, S.. 2023. "Wheat Prices Surge after Russia Ends Grain Deal. And It's Not Good News for the World's Food Supply." CNBC, July 17, 2023. https://www.cnbc.com/2023/07/17/russia-ukraine-grain-deal-what-does-it-mean-for-global-food-prices.html.

Molfar. 2023. "Who Exports Stolen Ukrainian Grain? Molfar Confirmed the Russian Scheme of Stealing Ukrainian Grain." https://molfar.com/en/blog/who-exports-stolen-ukrainian-grain.

Nazarkina, Roksolana, and Oleh Nivievskyi. 2023. "Did Black Sea Grain Initiative Help Ukrainian Farmers?" Vox Ukraine, Jul 4, 2023. https://voxukraine.org/en/did-black-sea-grain-initiative-help-ukrainian-farmers.

Nerlinger, Martin, and Sebastian Utz. 2022. "The Impact of the Russia-Ukraine Conflict on Energy Firms: A Capital Market Perspective." *Finance Research Letters* 50: 103243. https://doi.org/10.1016/j.frl.2022.103243.

Neyter, Roman, Hryhorii Stolnikovych, and Oleg Nivievskyi. 2022. "Agricultural War Damages Review, Ukraine Rapid Damage Assessment." Center for Food and Land Use Research, Kyiv School of Economics. https://kse.ua/wp-content/uploads/2022/06/Damages_report_issue1-1.pdf.

Nivievskyi, Oleg, and Roman Neyter. 2024. "Zwischenbilanz zum Krieg: Schaeden und Verluste der ukrainischen Landwirtschaft." *Ukraine-Analysen. Ausgabe* 294: 2–7. https://doi.org/10.31205/UA.294.01.

NYT. The New-York Times. 2023. "Russia Attacks Ukrainian Ports on Danube River." https://www.nytimes.com/2023/08/16/world/europe/russia-drone-attack-danube-port-ukraine.html.

OEC. The Observatory of Economic Complexity. 2021. "Ukraine Trade Data." https://oec.world/en.

Poursina, Davood, K. Aleks Schaefer, Sidany Hilburn, and Tuff Johnson. 2024. "Economic Impacts of the Black Sea Grain Initiative." *Journal of Agricultural Economics* 75(1): 457–464. https://doi.org/10.1111/1477-9552.12549.

Ritchie, Hannah. 2022. "Daily Calorie Supply: Data Sources and Definitions." Our World in Data. https://ourworldindata.org/calorie-supply-sources.

Rose, Adam, Zhenchua Chen, and Dan Wei. 2023. "The Economic Impacts of Russia-Ukraine War Export Disruptions of Grain Commodities." *Applied Economic Perspectives and Policy* 45(2): 645–665. https://doi.org/10.1002/aepp.13351.

Slovodilo. 2023. "Svyridenko Told How Much Agricultural Products Ukraine Exported this Year." https://www.slovoidilo.ua/2022/12/06/novyna/ekonomika/svyrydenko-rozpovila-skilky-ahroprodukcziyi-czoho-roku-eksportuvala-ukrayina.

Smith, Aaron. 2023. "How Did Russia's Invasion of Ukraine Affect Global Food Supplies?" *Choices* 38(2): 5–12. https://www.choicesmagazine.org/choices-magazine/theme-articles/turmoil-in-global-food-agricultural-and–input-markets-implications-of-russias-invasion-of-ukraine/how-did-russias-invasion-of-ukraine-affect-global-food-supplies#:~:text=The%20war%20has%20disrupted%20food,has%20disrupted%20global%20food%20supplies.

SSSU. State Statistics Service of Ukraine. 2022. "Statistical Yearbook of Ukraine 2021." Kyiv. https://ukrstat.gov.ua/druk/publicat/kat_u/2022/zb/11/Yearbook_21_e.pdf.

State Customs of Ukraine. 2024. "State Customs Service of Ukraine, 2024." Statistics of Trade. https://customs.gov.ua/en/statistika-ta-reiestri.

State Statistics Service of Ukraine. 2020. "Statistical Yearbook of Ukraine 2019." Kyiv. https://www.ukrstat.gov.ua/druk/publicat/kat_u/2020/zb/11/zb_yearbook_2019_e.pdf.

State Statistics Service of Ukraine. 2024. "Statistical Yearbook of Ukraine 2023." Kyiv. https://ukrstat.gov.ua

Steffen, Bjarne, and Anthony Patt. 2022. "A Historical Turning Point? Early Evidence on how the Russia-Ukraine War Changes Public Support for Clean Energy Policies." *Energy Research & Social Science* 91: 102758. https://doi.org/10.1016/j.erss.2022.102758.

SuperAgronom. 2023. "Due to the War, OSTCHEM Produced 66.9% Less Fertilizers in 2022." https://superagronom.com/news/16552-cherez-viynu-ostchem-vigotoviv-na-669-menshe-mindobriv-v-2022-rotsi.

Taera, Edosa G., Budi Setiawan, Adil Saleem, Andi S. Wahyuni, Daniel K. S. Chang, Robert J. Nathan, and Zaltan Laknerj. 2023. "The Impact of COVID-19 and Russia–Ukraine War on the Financial Asset Volatility: Evidence From Equity, Cryptocurrency and Alternative Assets." *Journal of Open Innovation: Technology, Market, and Complexity* 9(3): 100116. https://doi.org/10.1016/j.joitmc.2023.100116.

U.S. Office of the Director of National Intelligence. 2023. "Assessment of Impact of Russia's Invasion of Ukraine on Food Security." Washington, DC. https://files.constantcontact.com/fab49a91901/1e86de0d-671c-4652-9c56-dec0554e13a2.pdf.

UkrAgroConsult. 2023. "Global Trade in Cereals in 2022/23 Revised Down further, Forecast for 2023 World Wheat Production Up Marginally from Last Month." https://ukragroconsult.com/en/news/global-trade-in-cereals-in-2022-23-revised-down-further-forecast-for-2023-world-wheat-production-up-marginally-from-last-month/.

Ukrainian Agribusiness Club. 2022. "Forecast: In 2023, the Area Sown under Grain in Ukraine Will Decrease by 45%, and the Gross Harvest - by 60%." https://www.ucab.ua/ua/pres_sluzhba/novosti/prognoz_u_2023_rotsi_posivni_ploschi_pid_zernovimi_v_ukraini_skorotyatsya_na_45_a_valoviy_zbir__na_60.

UN. United Nations. 2023. "Update from the Office of the UN Coordinator for the Black Sea Grain Initiative." https://www.un.org/en/black-sea-grain-initiative/update-15-july-2023.

UN. United Nations. 2024. "Comtrade Database: Trade Data." https://comtradeplus.un.org/TradeFlow.

United Nations. 2024a. "The Black Sea Grain Initiative: What Was Achieved? Why Was It Important." https://www.un.org/en/black-sea-grain-initiative/achievements.

United Nations. 2024b. "Comtrade Database: Trade Data." https://comtradeplus.un.org/TradeFlow.

USDA. United States Department of Agriculture. 2022a. "Production, Supply, and Distribution." https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery.

USDA. United States Department of Agriculture. 2022b. "Ukraine Agricultural Production and Trade." https://www.fas.usda.gov/sites/default/files/2022-04/Ukraine-Factsheet-April2022.pdf.

USDA. United States Department of Agriculture. 2023. "Ukraine Agricultural Production and Trade. April 2022." Foreign Agricultural Service. https://fas.usda.gov//sites/default/files/2022-04/Ukraine-Factsheet-April2022.pdf.

von Cramon-Taubadel, Stephan. 2022. "Russia's Invasion of Ukraine – Implications for Grain Markets and Food Security." *German Journal of Agricultural Economics* 71(2): 1–13. https://doi.org/10.30430/71.2022.5.Apol.

von Cramon-Taubadel, Stephan, and Oleg Nivievskyi. 2023. "Rebuilding Ukraine – The Agricultural Perspective." *EconPol Forum* 24(2): 36–40.

World Bank. 2021. "World Bank Open Data: Ukraine." https://data.worldbank.org/country/UA.

Yagi, Michiyuki, and Shunsuke Managi. 2023. "The Spillover Effects of Rising Energy Prices Following 2022 Russian Invasion of Ukraine." *Economic Analysis and Policy* 77(c): 680–695. https://doi.org/10.1016/j.eap.2022.12.025.

Zhou, En, and Xinyu Wang. 2023. "Dynamics of Systemic Risk in European Gas and Oil Markets Under the Russia–Ukraine Conflict: A Quantile Regression Neural Network Approach." *Energy Reports* 9: 3956–66. https://doi.org/10.1016/j.egyr.2023.03.030.

How to cite this article: Countryman, Amanda M., Valentyn Litvinov, Ivan Kolodiazhnyi, Mariia Bogonos, and Oleg Nivievskyi. 2024. "Global Economic Effects of War-Induced Agricultural Export Declines from Ukraine." *Applied Economic Perspectives and Policy* 1–42. https://doi.org/10.1002/aepp.13468

APPENDIX A

FIGURE A1 ESL and BSGI main exports corridors. *Source*: Authors' elaboration based on United Nations (2023) and NYT (2023).

FIGURE A2 War effect on domestic wheat prices in Ukraine. Grain Deal is another term that is often used for the Black Sea Grain Initiative (BSGI). *Source*: Authors' elaboration based on price data from Ukragroconsult (2023).

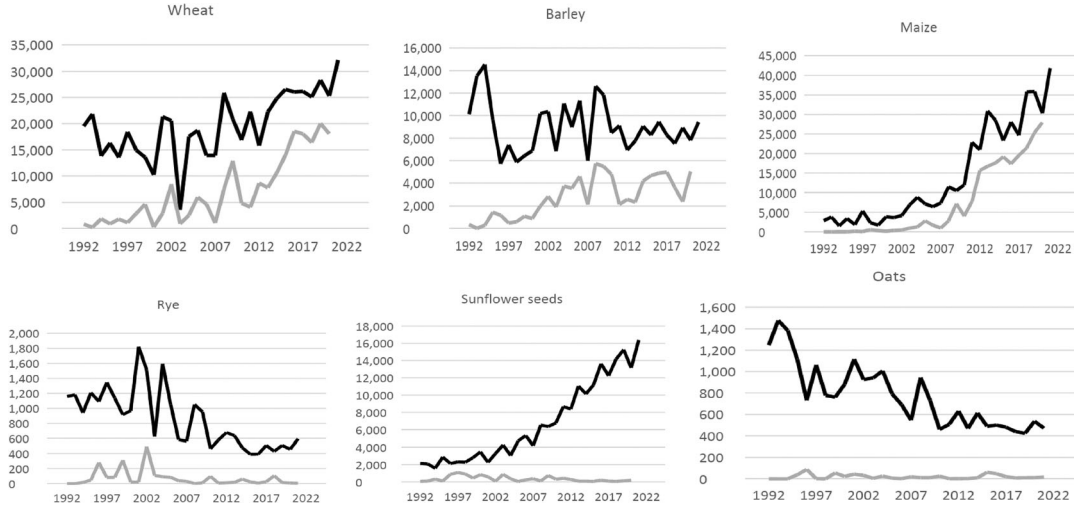

FIGURE A3 Production (black curve) and exports (gray curve) of grains and sunflower seeds in Ukraine from 1992 to 2021 in thousand tons. *Source*: SSSU (2022).

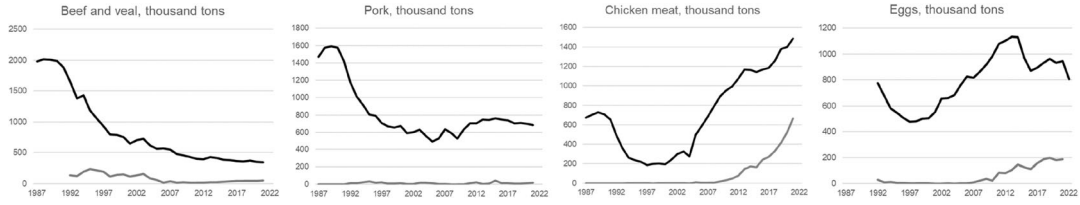

FIGURE A4 Production (black curve) and exports (gray curve) of livestock products in Ukraine. *Source*: SSSU (2022).

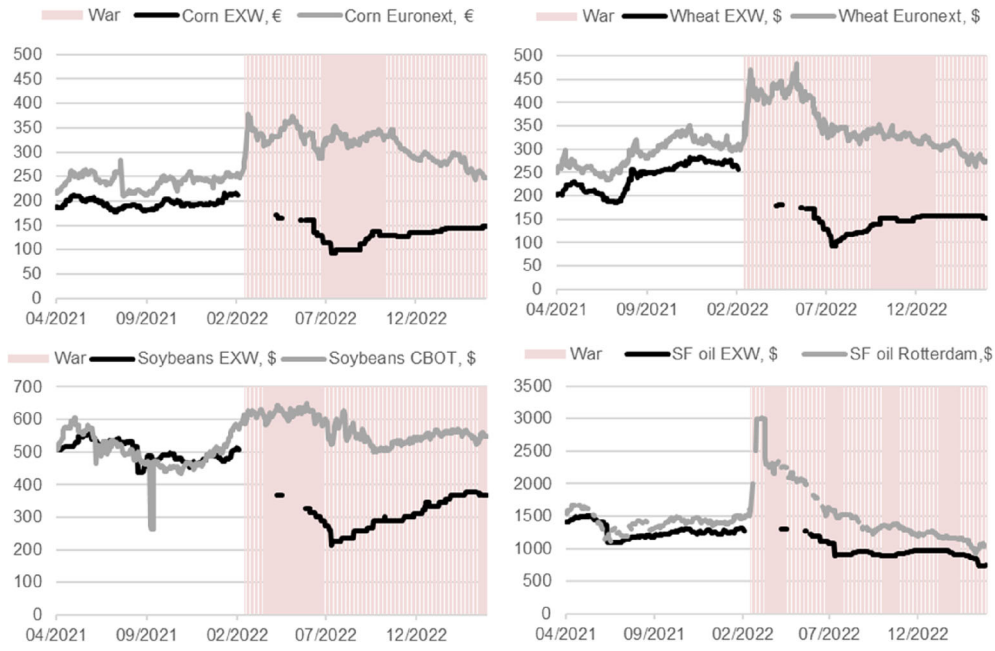

FIGURE A5 Grain prices in local and world markets from 2021 to 2023: (1) wheat prices; (2) corn prices; (3) soybean prices; (4) sunflower (SF) oil prices. Black Sea Grain Initiative European Routes. *Source*: Authors' representation based on Ukragroconsult (2023).

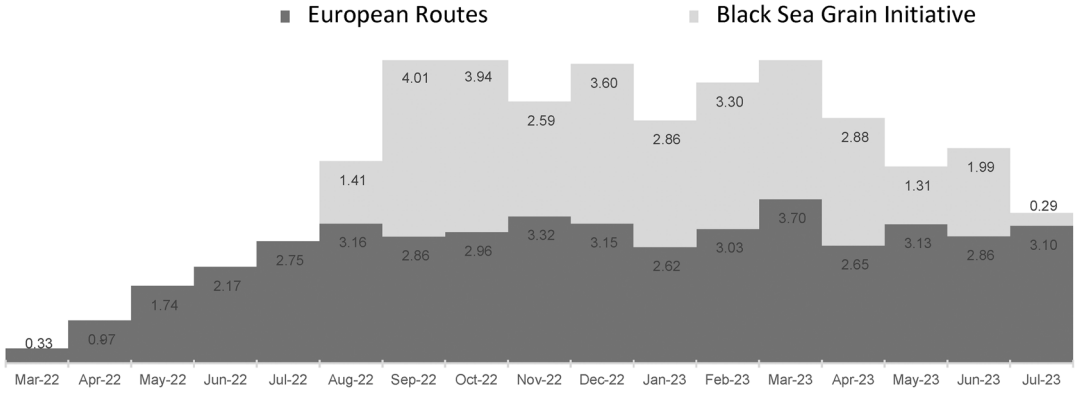

FIGURE A6 Wartime exports by transport route, million tons. *Source*: MAPF (2023).

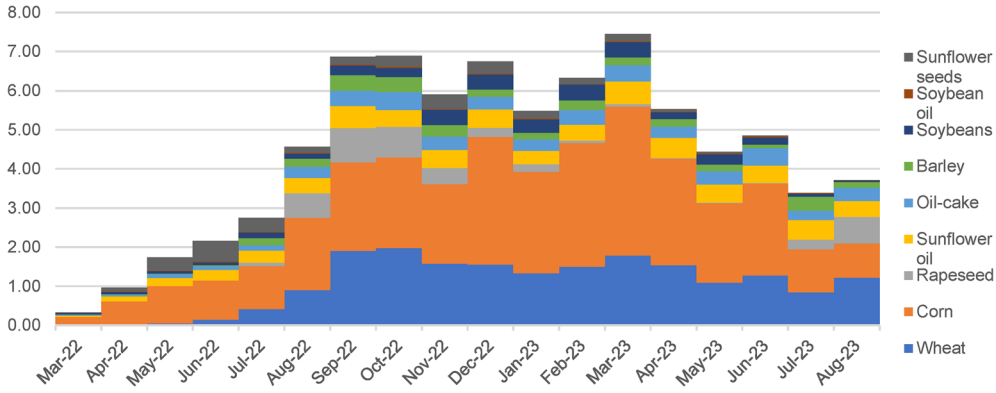

FIGURE A7 Wartime exports from Ukraine, million tons. *Source*: MAPF (2023).

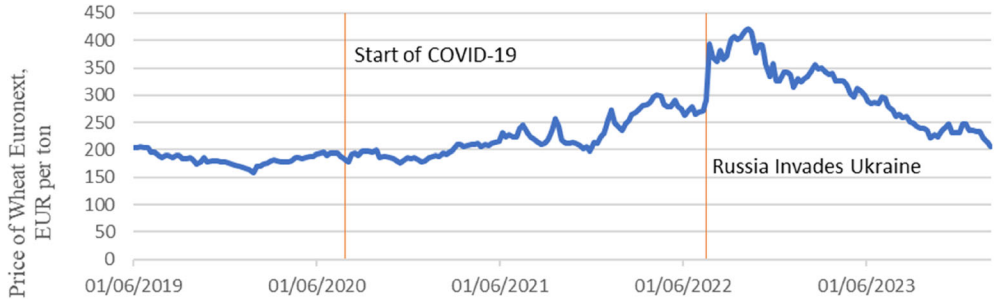

FIGURE A8 Euronext wheat prices from 2019 to 2023. *Source*: Authors' representation based on FAO (2024b).

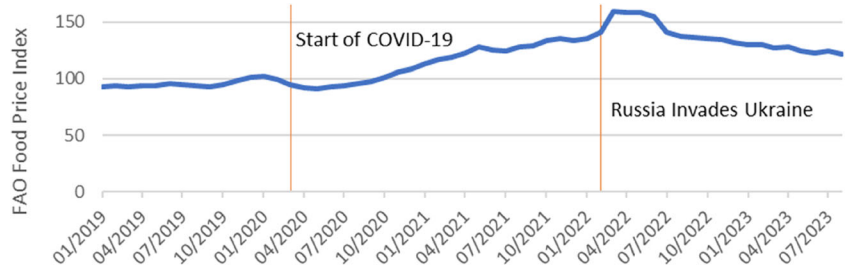

FIGURE A9 FAO Food Price Index from 2019 to 2023. *Source*: Authors' representation based on FAO (2024b).

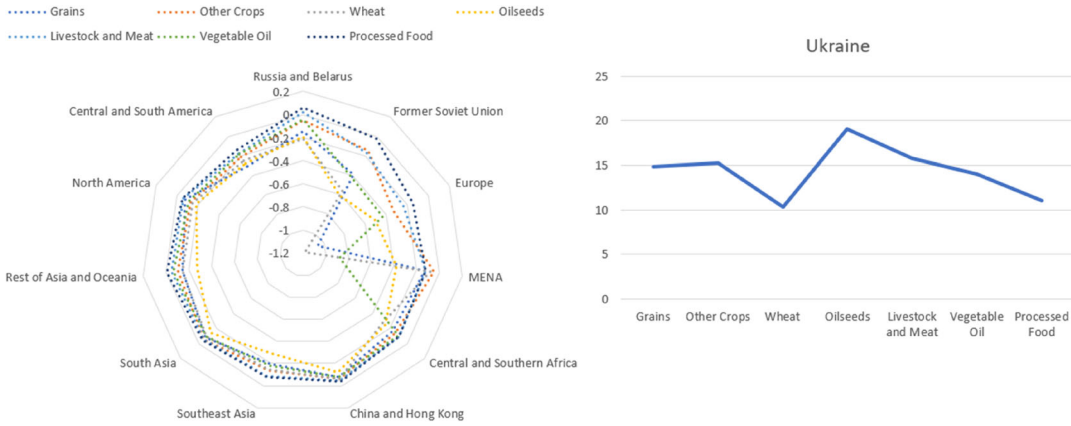

FIGURE A10 Differences in domestic price changes across regions and agricultural sectors between Scenario I: Weak European Solidarity Lanes and Scenario II: Strong European Solidarity Lanes. Table values show the results for Scenario I subtracted from Scenario II. Changes in prices in Ukraine are considerably greater than other regions and are indicated separately. *Source*: Authors' presentation using simulated outcomes.

TABLE A1 Regional aggregation.

GTAP code	GTAP country/region	Model aggregation
aus	Australia	Rest of Asia and Oceania
nzl	New Zealand	Rest of Asia and Oceania
xoc	Rest of Oceania	Rest of Asia and Oceania
chn	China	China and Hong Kong
hkg	Hong Kong	China and Hong Kong
jpn	Japan	Rest of Asia and Oceania
kor	Korea	Rest of Asia and Oceania
mng	Mongolia	Rest of Asia and Oceania
twn	Taiwan	Rest of Asia and Oceania
xea	Rest of East Asia	Rest of Asia and Oceania
brn	Brunei Darussalam	Rest of Asia and Oceania
khm	Cambodia	Southeast Asia
Idn	Indonesia	Southeast Asia
lao	Lao People's Democratic Republic	Southeast Asia
mys	Malaysia	Southeast Asia
phl	Philippines	Southeast Asia
sgp	Singapore	Southeast Asia
tha	Thailand	Southeast Asia
vnm	Viet Nam	Southeast Asia
xse	Rest of Southeast Asia	Southeast Asia
bgd	Bangladesh	South Asia
ind	India	South Asia
npl	Nepal	South Asia
pak	Pakistan	South Asia
lka	Sri Lanka	South Asia
xsa	Rest of South Asia	South Asia
can	Canada	North America
usa	United States of America	North America
mex	Mexico	North America
xna	Rest of North America	North America
arg	Argentina	Central and South America
bol	Bolivia	Central and South America
bra	Brazil	Central and South America
chl	Chile	Central and South America
col	Colombia	Central and South America
ecu	Ecuador	Central and South America
pry	Paraguay	Central and South America
per	Peru	Central and South America

(Continues)

TABLE A1 (Continued)

GTAP code	GTAP country/region	Model aggregation
ury	Uruguay	Central and South America
ven	Venezuela	Central and South America
xsm	Rest of South America	Central and South America
cri	Costa Rica	Central and South America
gtm	Guatemala	Central and South America
hnd	Honduras	Central and South America
nic	Nicaragua	Central and South America
pan	Panama	Central and South America
slv	El Salvador	Central and South America
xca	Rest of Central America	Central and South America
dom	Dominican Republic	Central and South America
jam	Jamaica	Central and South America
pri	Puerto Rico	Central and South America
tto	Trinidad and Tobago	Central and South America
xcb	Caribbean	Central and South America
aut	Austria	Europe
bel	Belgium	Europe
bgr	Bulgaria	Europe
hrv	Croatia	Europe
cyp	Cyprus	Europe
cze	Czech Republic	Europe
dnk	Denmark	Europe
est	Estonia	Europe
fin	Finland	Europe
fra	France	Europe
deu	Germany	Europe
grc	Greece	Europe
hun	Hungary	Europe
irl	Ireland	Europe
ita	Italy	Europe
lva	Latvia	Europe
ltu	Lithuania	Europe
lux	Luxembourg	Europe
mlt	Malta	Europe
nld	Netherlands	Europe
pol	Poland	Europe
prt	Portugal	Europe
rou	Romania	Europe

TABLE A1 (Continued)

GTAP code	GTAP country/region	Model aggregation
svk	Slovakia	Europe
svn	Slovenia	Europe
esp	Spain	Europe
swe	Sweden	Europe
gbr	United Kingdom	Europe
che	Switzerland	Europe
nor	Norway	Europe
xef	Rest of EFTA	Europe
alb	Albania	Europe
blr	Belarus	Russia and Belarus
rus	Russian Federation	Russia and Belarus
ukr	Ukraine	Ukraine
xee	Rest of Eastern Europe	Former Soviet Union
xer	Rest of Europe	Europe
kaz	Kazakhstan	Former Soviet Union
kgz	Kyrgyzstan	Former Soviet Union
tjk	Tajikistan	Former Soviet Union
xsu	Rest of Former Soviet Union	Former Soviet Union
arm	Armenia	Former Soviet Union
aze	Azerbaijan	Former Soviet Union
geo	Georgia	Former Soviet Union
bhr	Bahrain	MENA
irn	Iran Islamic Republic of	MENA
isr	Israel	MENA
jor	Jordan	MENA
kwt	Kuwait	MENA
omn	Oman	MENA
qat	Qatar	MENA
sau	Saudi Arabia	MENA
tur	Turkey	MENA
are	United Arab Emirates	MENA
xws	Rest of Western Asia	MENA
egy	Egypt	MENA
mar	Morocco	MENA
tun	Tunisia	MENA
xnf	Rest of North Africa	MENA
ben	Benin	Central and Southern Africa
bfa	Burkina Faso	Central and Southern Africa

(Continues)

TABLE A1 (Continued)

GTAP code	GTAP country/region	Model aggregation
cmr	Cameroon	Central and Southern Africa
civ	Cote d'Ivoire	Central and Southern Africa
gha	Ghana	Central and Southern Africa
gin	Guinea	Central and Southern Africa
nga	Nigeria	Central and Southern Africa
sen	Senegal	Central and Southern Africa
tgo	Togo	Central and Southern Africa
xwf	Rest of Western Africa	Central and Southern Africa
xcf	Central Africa	Central and Southern Africa
xac	South Central Africa	Central and Southern Africa
eth	Ethiopia	Central and Southern Africa
ken	Kenya	Central and Southern Africa
mdg	Madagascar	Central and Southern Africa
mwi	Malawi	Central and Southern Africa
mus	Mauritius	Central and Southern Africa
moz	Mozambique	Central and Southern Africa
rwa	Rwanda	Central and Southern Africa
tza	Tanzania	Central and Southern Africa
uga	Uganda	Central and Southern Africa
zmb	Zambia	Central and Southern Africa
zwe	Zimbabwe	Central and Southern Africa
xec	Rest of Eastern Africa	Central and Southern Africa
bwa	Botswana	Central and Southern Africa
nam	Namibia	Central and Southern Africa
zaf	South Africa	Central and Southern Africa
xsc	Rest of South African Customs	Central and Southern Africa
xtw	Rest of the World	Central and Southern Africa

Source: Authors' aggregation of the GTAPv11 Database.

TABLE A2 GTAP sectoral aggregation.

GTAP code	GTAP country/region	Model aggregation
pdr	Paddy rice	Other Crops
wht	Wheat	Wheat
gro	Cereal grains nec	Grains
v_f	Vegetables, fruit, nuts	Other Crops
osd	Oil seeds	Oilseeds
c_b	Sugar cane, sugar beet	Other Crops
pfb	Plant-based fibers	Other Crops
ocr	Crops nec	Other Crops
ctl	Bovine cattle, sheep, and goats	Livestock and Meat
oap	Animal products nec	Livestock and Meat
rmk	Raw milk	Livestock and Meat
wol	Wool, silk-worm cocoons	Livestock and Meat
frs	Forestry	Mining and Extraction
fsh	Fishing	Mining and Extraction
coa	Coal	Mining and Extraction
oil	Oil	Mining and Extraction
gas	Gas	Mining and Extraction
oxt	Minerals nec	Mining and Extraction
cmt	Bovine meat products	Livestock and Meat
omt	Meat products nec	Livestock and Meat
vol	Vegetable oils and fats	Vegetable Oil
mil	Dairy products	Processed Food
pcr	Processed rice	Processed Food
sgr	Sugar	Processed Food
ofd	Food products nec	Processed Food
b_t	Beverages and tobacco products	Processed Food
tex	Textiles	Textiles
wap	Wearing apparel	Textiles
lea	Leather products	Manufacturing
lum	Wood products	Manufacturing
ppp	Paper products, publishing	Manufacturing
p_c	Petroleum, coal products	Manufacturing
chm	Chemical products	Manufacturing
bph	Basic pharmaceutical products	Manufacturing
rpp	Rubber and plastic products	Manufacturing
nmm	Mineral products nec	Manufacturing
i_s	Ferrous metals	Manufacturing
nfm	Metals nec	Manufacturing

(Continues)

TABLE A2 (Continued)

GTAP code	GTAP country/region	Model aggregation
fmp	Metal products	Manufacturing
ele	Computer, electronic, and optic	Manufacturing
eeq	Electrical equipment	Manufacturing
ome	Machinery and equipment nec	Manufacturing
mvh	Motor vehicles and parts	Manufacturing
otn	Transport equipment nec	Manufacturing
omf	Manufactures nec	Manufacturing
ely	Electricity	Utilities and Construction
gdt	Gas manufacture, distribution	Utilities and Construction
wtr	Water	Utilities and Construction
cns	Construction	Utilities and Construction
trd	Trade	Transport
afs	Accommodation, Food and servic	Transport
otp	Transport nec	Transport
wtp	Water transport	Transport
atp	Air transport	Transport
whs	Warehousing and support activities	Transport
cmn	Communication	Other Services
ofi	Financial services nec	Other Services
ins	Insurance	Other Services
rsa	Real estate activities	Other Services
obs	Business services nec	Other Services
ros	Recreational and other service	Other Services
osg	Public Administration and defense	Other Services
edu	Education	Other Services
hht	Human health and social work	Other Services
dwe	Dwellings	Other Services

Source: Authors' aggregation of the GTAPv11 Database.

TABLE A3 Difference between domestic outputs between Scenario II: Strong European Solidarity Lanes and Scenario I: Weak European Solidarity Lanes.

Sectors	Ukraine	Russia and Belarus	Former Soviet Union	Europe	Middle East North Africa	Central and Southern Africa	China and Hong Kong	Southeast Asia	South Asia	Rest of Asia and Oceania	North America	Central and South America
Grains	39.41	−1.77	−1.20	−9.21	−1.61	−0.07	−0.12	−0.10	−0.06	−0.80	−0.03	−1.15
Other crops	2.40	−0.16	0.06	0.23	−0.05	−0.01	−0.01	0.02	−0.01	−0.04	−0.03	0.06
Wheat	64.37	−2.71	−2.64	−7.29	−1.13	−0.56	−0.01	−0.06	−0.16	−1.07	−1.24	−0.23
Oilseeds	45.42	−2.26	−2.52	−2.40	−5.39	−0.37	−0.32	−0.61	−0.30	−2.03	−0.90	−0.97
Livestock and meat	15.82	−0.05	−0.04	0.17	0.02	−0.02	−0.01	−0.01	0.00	−0.09	−0.02	0.03
Vegetable oil	43.69	−2.49	−3.24	−1.64	−0.48	−0.30	−0.07	−0.92	−0.51	−0.56	−0.26	−1.13
Processed food	3.62	−0.05	−0.09	0.13	0.05	−0.01	0.00	0.01	−0.01	−0.05	−0.01	0.03

Note: Table values show the results for Scenario I subtracted from Scenario II.
Source: Authors' presentation using simulations outcomes.

TABLE A4 Difference in aggregate exports between Scenario I: Weak European Solidarity Lanes and Scenario II: Strong European Solidarity Lanes.

Sectors	Russia and Belarus	Former Soviet Union	Europe	Middle East North Africa	Central and Southern Africa	China and Hong Kong	Southeast Asia	South Asia	Rest of Asia and Oceania	North America	Central and South America
Grains	−5.35	−9.2	−17.5	−6.07	−0.94	1.76	−1.18	−2.11	−2.33	−0.13	−3.43
Other crops	1.36	0.36	0.4	−0.22	−0.1	−0.33	0.01	−0.19	−0.08	−0.07	0.14
Wheat	−3.62	−6.47	−10.52	−9.15	−2.13	−3.73	−0.29	−3.43	−1.26	−2.18	−0.59
Oilseeds	−6.97	−5.73	−3.77	−4.98	−3.84	−7.46	−0.41	−2.88	−4.57	−1.49	−0.95
Livestock and meat	−0.46	0.23	0.37	−0.25	−0.38	−0.45	−0.24	−0.44	−0.38	−0.2	0.29
Vegetable oil	−6.36	−4.48	−2.48	−0.27	−1.55	−1.79	−1.35	−2.25	−3.04	−1.25	−2.55
Processed food	−0.1	0.29	0.21	0.06	0	−0.08	0.01	−0.14	−0.23	−0.09	0.18

Source: Authors' presentation using simulated outcomes.