Agricultural and Economywide Effects of the War in Ukraine

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Abstract

The war in Ukraine caused export disruptions that jeopardize 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 under varying success of alternate transport from Ukraine given inability to export through the Black Sea. Results show net global welfare effects ranging from more than $5 billion to nearly $20 billion depending on the success of transport through European Solidarity Lanes.

Introduction

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. As the world was recovering from the consequences of the COVID-19 pandemic, Russia began a full-scale invasion in Ukraine in February 2022. The war shocked global agricultural markets and world market prices soared through mid-2022 (Ihle et al., 2022). The Black Sea is a critical export supply route for Ukraine, and Black Sea ports were immediately blocked by the Russian naval fleet. Ukraine's inability to export through traditional channels forced grains and vegetable oil to remain in Ukraine's ports and in inland elevators (Martyshev et al., 2023). Concerns regarding agricultural commodity shortages arose as global stocks were at historic lows and markets were tight before the war began in Ukraine (Elleby, 2023; Glauber 2023b; Smith,

2023; von Cramon-Taubadel, 2022). Agricultural producers and exporters employed alternative but more costly trade routes, including transport overland via trucks and rail across Ukraine's western borders, and through Danube River ports. However, export capacity could not accommodate export supply. The Black Sea Grain Initiative (BSGI) was implemented in the summer of 2022 and allowed for much larger volumes of agricultural exports from Ukraine from August 2022 to July 2023. However, termination of the BSGI in July 2023 again limited Ukraine's export capacity to the Danube River and more costly European Solidarity Lanes (ESL). Concurrently, intensified shelling of the Danube River ports (NYT, 2023) and continued trade tensions between Ukraine and neighboring countries over Ukraine's increased grain exports into the European Union (EU) substantially weakens the transship capacities of the ESL (WSJ, 2023). The complexities of continued war and concerns regarding Ukraine's export potential elevates uncertainty and food security concerns around the world with developing nations especially vulnerable. This research employs a computable general equilibrium (CGE) modeling framework to investigate the economywide effects of war-related disruptions in agricultural exports from Ukraine and investigates the implications of whether the ESL capacity is weak or strong. This manuscript proceeds as follows. First, we provide a description of agricultural exports from Ukraine and how agricultural markets have been affected since the war began in 2022 including changes in transportation routes and exports. We then provide context for Ukraine's agricultural sector before the war and highlight studies of the effects of the war in Ukraine. Next, we describe the data, methods, and export scenarios we investigate and analyze results. We conclude with a discussion of key findings and implications of this research.

The Importance of Ukraine in Global Agricultural Markets

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 1 and 2), 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).

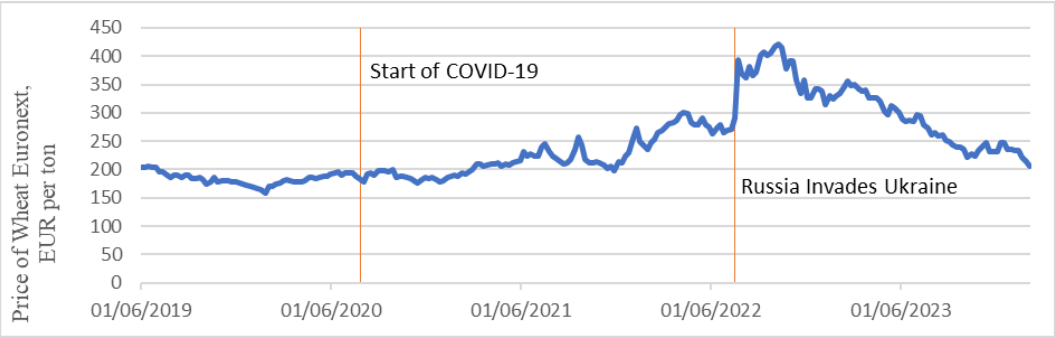


Figure 1. Euronext Wheat Prices from 2019 to 2023
Source: Authors' representation based on FAO data

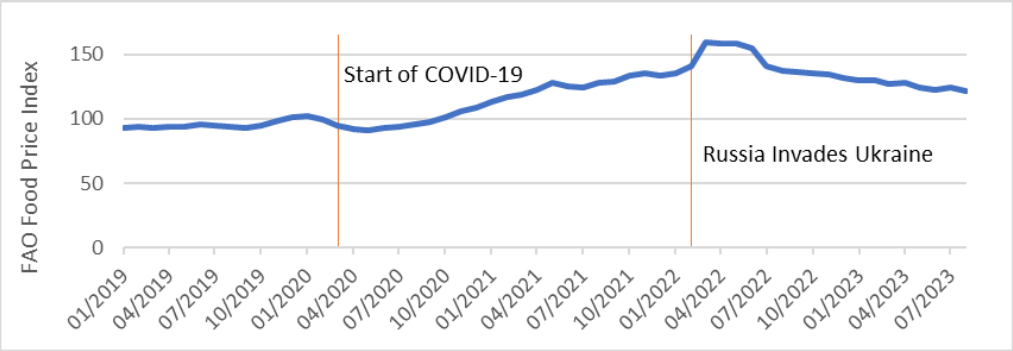


Figure 2. FAO Food Price Index from 2019 to 2023
Source: Authors' representation based on FAO data

Before the full-scale Russian invasion, Ukraine supplied approximately 50% of global sunflower oil and nearly two-thirds of sunflower meal exports. The main destination markets were China (48%), the EU (25%), and Turkey (7%). Ukraine was the third largest exporter of rapeseeds, and seventh largest exporter of soybeans. The country ranked fourth in corn exports, with top destinations including China, EU, Egypt, Iran, and Turkey. Ukraine was the seventh largest wheat exporter, with Egypt, Indonesia, Turkey, Pakistan, and Bangladesh being its

main export destinations. In the 2021/22 marketing year, Ukraine was expected to be the fifth largest wheat exporter (USDA, 2022). Middle East and North African countries strongly depend on Ukrainian wheat, with import dependency often reaching 50% (e.g. Eritrea) and even higher in some cases (e.g. Egypt, Turkey and Iran) (FAO, 2022; Smith, 2023). In 2020, Lebanon imported 61.5% of its wheat from Ukraine (OEC, 2021). After the blockade of Ukrainian exports, the price of bread in Lebanon increased by an astonishing 70% (IPES-FOOD, 2022). Other African countries are also exposed to import dependency and high price volatility, including Sudan, Kenya, Ethiopia, and Somalia as the most vulnerable (Breisinger et al., 2023a; Breisinger et al., 2023b; Abay et al., 2023). Other countries, like Burundi and Rwanda, indirectly dependent on Ukraine's sunflower oil through re-exports from Egypt (EU Commission, 2022). The prices of cooking vegetable oil, bread, and wheat flour have increased dramatically with fuel prices and the cost of living rising in tandem. 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 are experiencing similar challenges given import dependency on wheat supplies from Ukraine and Russia to meet domestic demands for noodles and bread (US Global Leadership Coalition, 2022; Mamum et al, 2023).

The ongoing war in Ukraine jeopardizes global food security and puts pressure on commodity markets (Glauber, 2023). Global agricultural commodity prices increased substantially after the Russian invasion of Ukraine and then decreased but remain high. Inflation has been greater than 5% for almost all low- and middle-income countries (FAO, 2023). Trade disruption is another result of the conflict, as it became riskier to supply from Ukraine and Western sanctions were imposed on Russian goods in response to the invasion (Glauber and Laborde, 2023). After sixteen months into the war, the intensive fighting has been localized to the Eastern and Southern parts of Ukraine (Kherson, Zaporizhzhia, Donetsk

and Luhansk oblasts and Crimea). However, the regional centers throughout the country and critical infrastructure, such as roads, ports, storage facilities, and power stations continue to suffer from Russian missile and drones strikes. As of June 2023, the total estimated damages to Ukraine were $150.5 billion USD, which is close to the value of Ukraine's 2022 GDP. 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) (KSE 2023).

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 have 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. The three most damaged asset groups are machinery ($4.62 billion), stored commodities ($2 billion), and storage facilities ($1.3 billion). 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 (Novoe Vremya, 2023; Suspilne, 2023a). This land is dangerous for civilians and is no longer suitable for any kind of economic activity including agricultural production. The cost to clear the land from hazardous material is currently estimated at $37.6 billion (Neyter et al., 2023). Lost territory and damage to the agricultural sector translates into millions of tons of forgone output and exports of cereal and oilseeds. The most substantial drop 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 seasons (MAPF, 2023; Ukrainian Agribusiness Club, 2022).

Despite destruction from war, agricultural producers suffer tremendously from a domestic price crisis. Severely reduced export capacities and a lack of alternative export routes critically increased logistics costs that eventually depressed farm-gate prices in Ukraine approximately by a factor of two as illustrated in Figure 3 (Martyshev et al., 2023). 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 (Neyter et al., 2023). Furthermore, there was a shortage of inputs when fertilizer became unavailable from Ostchem, one of the major domestic fertilizer producers in Ukraine, which is in the temporarily occupied city of Severodonetsk in the Luhansk region. Ostchem decreased fertilizer 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. 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, 2023). The combined effects of occupied land, war-related damages, increased fertilizer prices, and decreased input availability led to decreased planting and yields throughout Ukraine after the 2022 invasion.

Figure 3. Grain prices in local and world markets from 2021-2023: 1) wheat prices; 2) corn prices; 3) soybean prices, 4) sunflower (SF) oil prices

Source: Authors' representation based on Ukragroconsult data (2023)

Turkey and the UN 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 (UN, 2022). The corridor allowed increased agricultural exports from Ukraine starting in August 2022 (Glauber and Laborde 2022); however, the corresponding effects on domestic prices were minor and only marginally improved domestic producer incomes (Nazarkina and Nivievskyi, 2023). While the BSGI facilitate increased grain exports, export costs remained high and close to pre-BSGI levels, and domestic prices stayed depressed. Moreover, by persistent threats to leave the agreement, delaying vessel inspections, Russia persistently undermined trust regarding the functioning of the BSGI that kept risks and costs of grain corridor shipments high (UkrAgroConsult, 2022). Eventually, Russia withdrew from the BSGI in July 2023. (UN, 2023).

The EU launched the ESL in May 2022 to facilitate exports through the western borders of Ukraine, by roads, rail, and river ports (EU Commission, 2022). Since the dissolution of the BSGI, exports of agricultural commodities through the ESL by railways have reached

approximately 1 million tons per month, and river port export capacities increased to approximately 2.8 million tons per month (Figure 4). However, right after the BSGI dissolution, Russia started persistently targeting the Danube port infrastructure causing further increased export costs (NYT, 2023). Overall, agricultural export costs increased threefold after the invasion: from pre-war $30 to $40 per ton, then peaking at about $200 per ton early in 2022 before stabilizing at $125-150 per ton (Martyshev et al, 2023). Now, with increased shelling of river ports and the absence of the BSGI, export costs increased by approximately 10% and the ESL role became critical (CNBC, 2023).

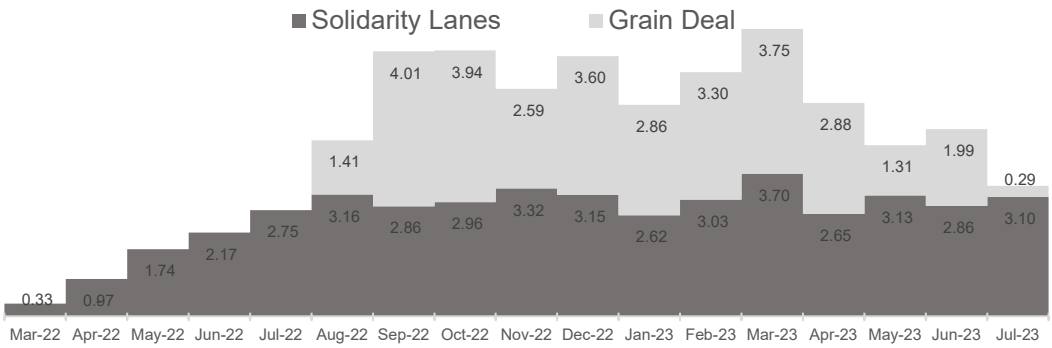


Figure 4. Wartime Exports by Transport Route, million tons
Source: Ministry of Agrarian Policy and Food (MAPF) of Ukraine 2023

Despite the opening of transport through 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 2022 to 2021. However, oilseed exports unexpectedly doubled over the same timeframe because export prices for seeds were more favorable than domestic crush prices, causing producers to export oilseeds. This led to a 15% decrease in total vegetable oil exports including 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)), and a reduction in domestic vegetable oil stocks. 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). Despite challenges, corn

remains the dominant export crop due to its large stocks and proximity to primary export destinations, notably EU countries as illustrated in Figure 5. 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. Meanwhile, sunflower seed exports have been relatively high, which is not typical for Ukraine (APK-Inform, 2022). Usually, more than 95% of the seeds are crushed and exported as meal and oil (USDA, 2022). The main reason that sunflower seed exports increased in 2023 is because of relatively high export prices for seeds relative to domestic crush prices. So, selling seeds to local crushers was less profitable than exporting, even with considerably increased transportation costs and railway congestion at the western borders (MAPF, 2023). Ukraine's exports did not reach pre-war levels even with increased exports through the BSGI and ESL.

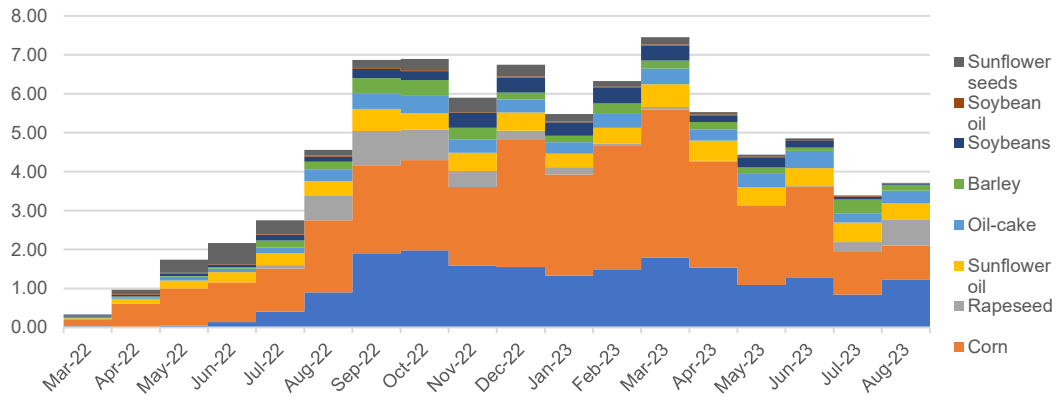


Figure 5. Wartime Exports from Ukraine, million tons
Source: Ministry of Agrarian Policy and Food of Ukraine 2023

Ukraine's Agricultural Sector Before the War

Historically, Ukraine was considered a breadbasket for neighboring and more distant regions in Europe and in USSR during the soviet era. Ukraine has one-third of the world's most fertile black soils and 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

agricultural land in the country is used to produce cereals, oilseeds, vegetables, and other annual crops (World Bank, 2021; SSSU, 2020a). In 2021, primary agriculture contributed almost 10% of Ukraine's GDP, 18% of employment, and 44% of 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 and Nivievskyi, 2023). Since 1992, crop production has dominated Ukrainian agriculture (Figure 6). While production of wheat and maize has been growing, barley quantities remained steady in the decade before the war and oat and rye production decreased over the same period. Maize production grew from 3.8 million tons to 41.9 million tons from 2000 to 2020 mainly in response to increased export demand. Sunflower is the traditional oil crop for Ukraine, and production has been increasing steadily since the 1990s. Starting from 2000, sunflower oil production and exports also increased. Rapeseed and soybean production was also growing rapidly before the war, though on much smaller areas of agricultural land relative to other crops (SSSU, 2022).

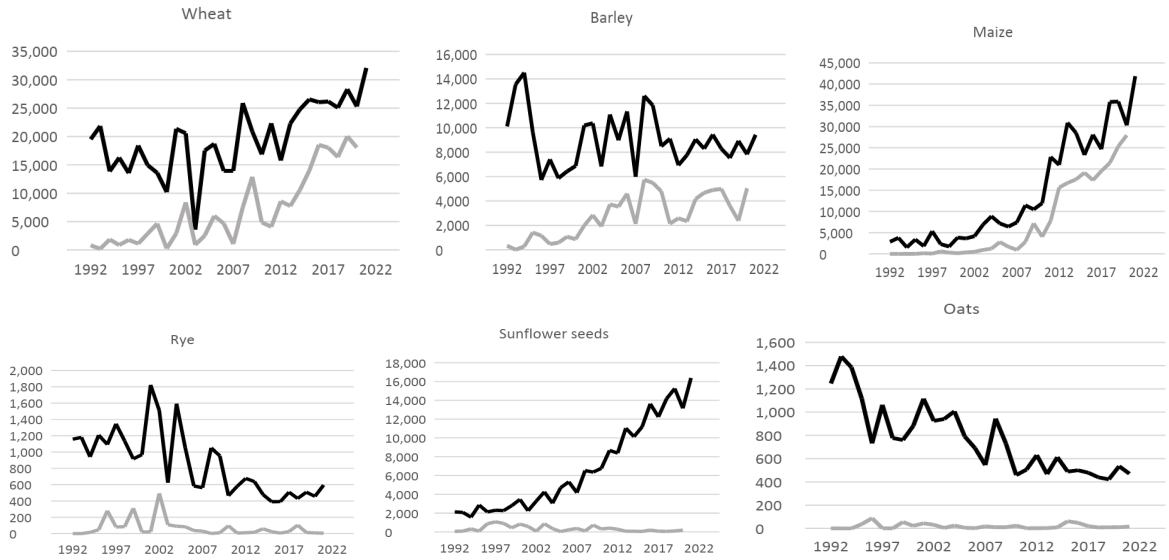


Figure 6. Production (black curve) and exports (gray curve) of grains and sunflower seeds in Ukraine from 1992 to 2021 in thousand tons
Source: SSSU 2022

In contrast to crops, livestock production and exports outcomes vary over time and across the subsectors as illustrated in Figure 7. The livestock in Ukraine is generally represented by

two large groups: rural households and agricultural enterprises. Reductions in cattle and swine herds during the transition period since 1992 led to decreased production of beef and veal, milk, and pork. However, the fall in swine numbers slowed after 2006, and pork production stabilized at around 700 thousand tons. Sheep and goat herds and corresponding output of wool and milk declined steadily over time (SSSU, 2022). Like other livestock products, chicken meat and egg production declined from 1991 to 1996 and then began to increase in 2000. Chicken meat production grew from 193 thousand tons in 2000 to 1.6 million tons in 2021. Chicken egg production grew by 124% from 2000 to 2013, then dropped by 28% after the start of the 2014 invasion in the eastern part of Ukraine. Agricultural enterprises produce 89% of chicken meat and 56% of eggs. The remaining 11% and 44%, respectively, are produced by rural households (SSSU, 2020c; Tarasevych, 2020; SSSU, 2020d). Ukraine exported nearly 42.7 thousand tons of beef and imported 1.4 thousand tons of beef in 2018. Pork exports were 2.2 thousand tons and imports were 30 thousand tons in 2018. Chicken meat exports grew from approximately 1 thousand tons in 2000 to 665.9 thousand tons in 2021, and egg exports grew from around 1 thousand to 187.9 thousand tons (FAO, 2022; SSSU, 2020b; SSSU, 2020c; SSSU, 2011). Imports remain relatively low and less than 200 thousand tons for chicken meat, and 7 thousand tons for eggs.

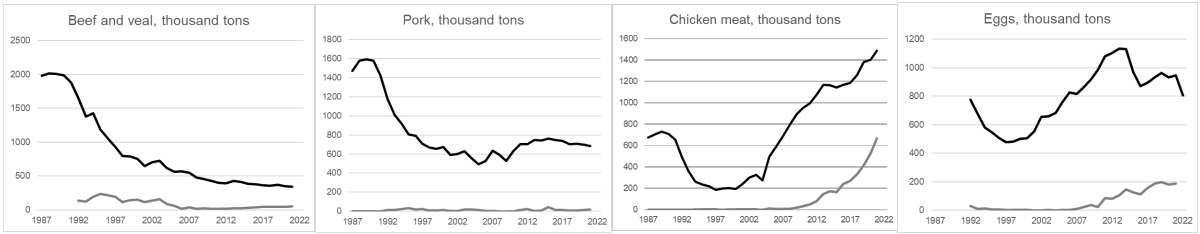


Figure 7. Production (black curve) and exports (gray curve) of livestock products in Ukraine
Source: State Statistics Service of Ukraine (SSSU) 2022

In the last decade, five main types of agricultural producers emerged in Ukraine: rural households, family farms, private enterprises, public enterprises, and agricultural holdings. Rural households currently cultivate land parcels of around 1.3 hectares. In 2019, rural

households produced 30.1% of Ukrainian crops and 48.7% of livestock commodities valued in current prices. Family farms, public enterprises, and private enterprises differ from each other by the type of ownership. Family farms are privately owned and operated mainly by family members (Law of Ukraine, 2003). The average size of a family farm is approximately 134 hectares. Private agricultural enterprises are defined as enterprises whose main economic activity is agricultural production with an average of 1.2 thousand hectares of land. Along with rural households, private enterprises are the main contributors to gross agricultural output in Ukraine (Bogonos and Stepaniuk, 2017; SSSU, 2020b). Public enterprises are owned by the state and includes 8.7 million hectares of agricultural land (Bogonos and Stepaniuk, 2017; SSSU, 2020b). Agricultural holdings are organized around parent companies that control and manage dozens of subsidiary agricultural enterprises and cultivate from around ten to more than 600 thousand hectares. Because such parent companies do not always own the subsidiary enterprises or their majority stocks, the term "holding" may be somewhat misleading (Hermans et al., 2017). Land ownership in Ukraine has implications for the land market and agricultural production. Although agricultural production in Ukraine has been growing over the past two decades, the agricultural land market was only recently introduced. Ukraine began to reform agricultural land ownership with the collapse of the Soviet Union and the declaration of independence in 1991. Land reform followed a complex history of agricultural land ownership being based on centralized planning and public ownership to market-based and private ownership. From the end of the 1990s until now, there are three types of property rights for agricultural land in Ukraine: public (8.7 million hectares), communal (1.7 million hectares), and private (31.0 million hectares). Due to a moratorium imposed on land sale transactions, none of this property could be sold or purchased under general circumstances until July 2021. Therefore, the most common agricultural land transactions included inheritance and emphyteusis (around 18% of transactions) and long- and short-term leasing (around 76% of

transactions) (Nizalov et al., 2018). In 2018, the average rental price for a hectare of agricultural land in Ukraine was approximately 50.2 euros per year in current prices (USSGCC, 2019). In July 2021, following the regulation adopted in 2020 (Law of Ukraine, 2020a), the moratorium on market transactions of agricultural land was lifted. However, some limitations remain. Agricultural land of public property, foreign legal entities and foreign individuals are exempted from the market, and domestic legal entities were also exempt until July 2023. As of 2021, agricultural land may only be purchased by Ukrainian citizens with a maximum purchase of 100 hectares, but from 2024 onwards, land purchases of up to 10 thousand hectares will be possible for legal entities if the beneficiaries are Ukrainians that have no business abroad or offshore companies (Forbes UA, 2023).

The Association Agreement between Ukraine and the EU largely defines agricultural reforms in Ukraine. The Association Agreement entails a comprehensive program of market and institutional reforms, whereas its trade component, Deep and Comprehensive Free Trade Area (DCFTA), defines the stages of trade liberalization and institutional convergence between the EU and Ukraine. Following the DCFTA, Ukraine began the introduction of the EU's technical requirements for food production, standardization, compliance assessment, surveillance, and sanitary and phytosanitary measures. Tariff-free import quotas allowed the agricultural sector to benefit from increased exports to the EU. The reform process was enhanced through cooperation with the International Monetary Fund. Adoption of a flexible exchange rate, inflation targeting policy, banking reforms, and abolishing the special value added tax regime played a significant role in the development of the Ukrainian agricultural sector (Kvasha et al., 2021; Nykolyuk et al., 2021). Ukraine has signed 12 bilateral and multilateral trade agreements since 1995. The first free trade agreements (FTA) were with Turkmenistan (1995), Georgia (1996) and Azerbaijan (1996). An FTA with the Republic of Northern Macedonia began in 2001. Ukraine became a member of the World Trade

Organization in 2005. Concurrently, import tariffs on non-sensitive foodstuffs and agricultural products, as well as many specific tariffs, were reduced to Most-Favored Nations (MFN) tariff levels. Ukraine joined the European Free Trade Association (EFTA) with Iceland, Liechtenstein, Norway, and Switzerland in 2012, and established an FTA with Montenegro in 2013. The Commonwealth of Independent States Free Trade Area among Ukraine, Armenia, Belarus, Kazakhstan, Kyrgyz Republic, Tajikistan, Uzbekistan, Moldova, and Russia became effective in 2012 as well. However, Russia and Ukraine suspended the FTA between each other on January 1, 2016, given persistent tensions. Ukraine signed FTAs with Canada in 2017, the State of Israel and Great Britain in 2021, and Turkey in 2022. Ukraine's continued efforts to expand trade relationships through trade policy liberalization led to expanded exports of agricultural products since the mid-1990s.

Studies on the Effects of the War in Ukraine

There is a rich and growing literature on the economic effects of the war in Ukraine. Methods employed include computable general equilibrium modeling, partial equilibrium 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 other markets. We provide a thorough review of the current literature on the economic effects of the war in Ukraine organized by each key thematic area.

Studies provide a comprehensive analysis of how the war between Russia and Ukraine affects agricultural markets and food security. In the first four weeks of the full-scale invasion, 16% of globally traded calories were impacted by protectionist food export restrictions that were implemented across 21 commodities by 14 countries because of concerns about potential food shortages, while licensing restrictions were imposed on 8 products across 7 countries. Russia's export bans on agricultural products impacts approximately 4.4% of global trade in

calories, while Ukraine's restrictions on exports of oats, millet, buckwheat, sugar, salt, rye, livestock and livestock commodities affected about 4.2% of global calories traded. Other countries that imposed export restrictions include Indonesia, Turkey, and Argentina (Laborde and Mamun, 2022). Research estimates that an additional 27.2 million people have been pushed into poverty, and another 22.3 million people have fallen into hunger as a direct result of the war. Agricultural systems and poverty levels are particularly vulnerable to spikes in fuel and fertilizer prices, while food insecurity and diet quality deteriorate mainly due to rising food costs (Arndt et al., 2023).

Simulation results by Chowdhury et al. (2023) for the effects of the war on Bangladesh indicate a 0.36% decrease in real national GDP, with energy price shocks being the most detrimental, contributing to a 0.28% reduction in real GDP. Notably, agricultural and service sectors, which are heavily reliant on petroleum products, are adversely affected by the war. Even a slight increase in international fertilizer prices has a negative impact on agriculture, especially affecting rice farmers in Bangladesh who are substantial users of fertilizer. The study estimates that around three million people could fall into poverty due to global commodity price shocks, the majority of whom reside in rural areas (Chowdhury et al., 2023). Glauber et al. (2022) explores the ripple effects of the war on global food security, emphasizing the vulnerabilities of import-dependent countries with low per capita incomes. The authors note the need for open and competitive international agricultural markets and robust global supply chain structures to mitigate potential food shortages. Research reveals that insulating policies roughly doubled the overall global increase in wheat prices, while also increasing wheat price volatility during times of both rising and falling prices (Martin et al., 2023). Studies show that corn prices play a pivotal role in driving price changes in wheat, barley, and sunflower oil and that wheat prices also influence the prices of other commodities,

albeit to a lesser extent than corn (Aliu et al., 2022). Laber et al. (2023) investigate the impacts of the Russia-Ukraine war on global food availability, emphasizing the interconnectedness of the international food production network. Using a multilayer network model, the study assesses the impact of localized agricultural production shocks in 192 countries and territories across 125 food products. The research quantifies 108 shock transmissions, unveiling the heterogeneous consequences of agricultural production losses in Ukraine. Direct effects lead to substantial relative losses in products like sunflower oil (89%) and maize (85%), while indirect impacts result in losses of up to 25% in poultry meat. Beckman and Ivanic (2023) employ the GTAP model to investigate scenarios including production losses, export losses, changes in labor supply in both Russia and Ukraine, and decreased domestic prices for energy in Russia in 2022. The authors find that decreased exports from Ukraine are the key driver 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 partial equilibrium 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. 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 and highlight the time that will be needed to rebuild Ukraine's export infrastructure after the war. Bullock et al. (2023) employ 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. In the time series analysis of reduced-form representation of commodity price co-movement by Poursina et al. (2023), the economic effects of the BSGI on global wheat and corn prices are estimated, and the authors determine the economic value of the BSGI for the global food system along with the regional distribution of welfare savings attributable to the BSGI. The findings indicate that the Russian Invasion resulted in around $116.05 billion in

economic costs in global wheat and corn markets. The BSGI brought a 7.9% reduction in international wheat prices, offsetting about $21.48 billion of the additional expenses incurred because of the war. The primary beneficiaries of the initiative, aside from Ukraine, are developing countries in the Middle East and North Africa. However, there are no significant discernible impacts of the initiative in the international corn market. Hebebrand and Glauber (2023) delves into the impact of the Russia-Ukraine war on global fertilizer markets and its consequences for agricultural production and food security. Despite the war's continuation into a second year, fertilizer prices have decreased from their peak in 2022, which was attributable to rising natural gas and coal prices coupled with disruptions in supply chains. Sanctions and export restrictions add to the complexities related to the conflict and further affect trade flows. Although high-income countries can secure alternative sources as substitutes for Ukrainian agricultural products, low-income nations face difficulties. Despite easing prices and increased availability through the BSGI, high domestic price inflation persisted, challenging affordability. Fan et al. (2023) examines the impact of the Russia-Ukraine war on global food security and trade patterns, using a Structural General Equilibrium Trade Model. The study considered a hypothetical scenario wherein Ukraine's agricultural production declines by 50%, Ukrainian trade is completely halted, and Russian trade decreases by 50%. Based on counterfactual analyses across multiple countries and sectors, the study finds substantial disruptions in global agricultural prices and food security. Results show agricultural prices increase by 10% to 30% and purchasing power for agricultural goods decreases by 15% to 25%. Countries that heavily rely on grain imports from Ukraine and Russia, such as Egypt and Turkey, would be severely affected because of agricultural price increases ranging from 10% to 30%, and severe food insecurity with decreased purchasing power for agricultural goods ranging from -15% to -25%. However, major agricultural exporters including the United States, Canada, and Australia are simulated to benefit from the war because of higher

commodity prices and ability to supply agricultural products, which is consistent with the positive effects simulated for U.S. agricultural producers that benefit from higher output prices relative to increased production costs (Westhoff et al., 2023). Trade restrictions on energy and fertilizer, commodities where Russia plays a significant role, are expected to amplify the negative impact on food security. The study's findings are consistent with real world data from 2022. For instance, the Chicago Board of Trade reported a 22%, 8%, and 18% year-over-year increase in wheat prices between July and September 2022. Wheat imports from countries like Pakistan, Egypt, and Uzbekistan declined significantly, ranging from 18% to 37% after the onset of the war (UN Comtrade, 2022).

The study by Babar et al. (2023) explores how various crises, including the COVID-19 pandemic and the Russia-Ukraine war, have affected the relationship between agricultural commodities and emerging stock markets. Utilizing the generalized spillover index, which is based on the contribution to a variable's forecast error variance coming from all other variables' shocks in the system — the "spillover" inherent in the system — and relies on the generalized forecast error variance decomposition for a vector autoregression (VAR) model, the research finds that there is a generally weak connection between agricultural commodity markets and emerging stock markets. The study also reveals that volatility spillovers increased during the crises, particularly during the COVID-19 pandemic. These findings provide valuable insights for investors and portfolio managers to make more informed decisions, particularly in times of crisis. The study by Ihle et al. (2022) examines whether commodity prices become more aligned following the invasion. Using a concordance index, the research analyzes 15 key global commodity price indicators from the World Bank and discovered that disruptions in supply chains increased correlation between prices for essential goods like grain, energy, and fertilizers worldwide. This effect extended beyond directly impacted items, influencing both food and non-food markets, which can lead to food insecurity and rising prices given limited

availability of affordable substitutes. This situation particularly affected vulnerable populations in the Global South, as they rely heavily on limited social security systems.

The research on the impact of the war on energy markets provides a wide array of findings. Research shows that if a war-induced 20% price surge is localized to Russia's mining and quarrying (M&Q) sector, the global impact would be minimal. However, if such a price increase occurs globally in the M&Q sector, results show a substantial 3.15% rise in global industrial prices that would lead to a 6.83% decrease (-$551 billion) in monthly global GDP. Furthermore, studies show that the Russia-Ukraine war has had a significant impact on systemic risk in both European gas and oil markets and that there has been a significant increase in support for clean energy policies due to the war (Yagi and Managi, 2022; Zhou and Wang, 2023; Nerlinger and Utz, 2022; Steffen and Patt, 2022).The impacts of the invasion on other markers include negative market responses before and after the announcement of the war. The conflict in Ukraine disrupted global logistics and connectivity across various transportation modes, short-term negative effects on Chinese manufacturing output, and more substantial medium- and long-term effects in the U.S. and EU (Yudaruddina et al., 2023).

The studies on war impacts related to energy markets provide insights into the multifaceted global economic consequences of the Russia-Ukraine conflict, highlighting the significance of energy dependence, trade dynamics, and government policies in shaping outcomes. For example, D. Colgan et al. (2023) quantified Europe's financial burden due to the invasion, estimating additional market costs of €517–831 billion, mainly driven by soaring fossil fuel prices. Camelia Negri and Gheorghiţa Dincă's study (2023) focused on the war's impact on EU economic output, showing a decline of €405.08 in GDP per capita for countries heavily reliant on Russian energy imports. Ajeigbe's research (2023) delved into the war's consequences on trade flows and Foreign Direct Investment (FDI), highlighting the impact on EU member states, especially those dependent on Russian energy. Liadze et al. (2022) used the NiGEM

model to simulate a 1% decrease in global GDP in 2022, amounting to approximately $1.5 trillion, with Europe being the most affected region due to its energy and food dependencies on Ukraine and Russia. Chepeliev et al.'s study (2022) explored the war's effects on global trade and income levels, revealing a 1% decline in global trade, with developing countries experiencing slightly higher export declines. Income effects varied, with some countries benefiting from higher commodity prices, while others faced income declines, primarily due to energy price spikes.

Renata Karkowska, Szczepan Urjasz., 2023 explore how the Russian-Ukrainian war impacted volatility spillovers in energy markets in comparison to global stock indices. The study uses data from August 1, 2014, to May 27, 2022, and includes 12 variables from three geographical regions: Asia, Europe, and the USA. The results indicate that the U.S. market remains dominant in international volatility transmission while the Asian market mostly receives spillover effects, particularly in times of crisis. Volatility spillovers are not consistent over time or across different types of energy. Additionally, clean energy indices are emerging as significant volatility transmitters to stock markets. Hedging in renewable energy assets is more costly compared to non-renewable energy.

A group of studies on the impact of the war on financial markets discovered four key findings. First, global stock markets had a strong negative reaction in the first two weeks following the invasion, and second, there was increased volatility across nearly all asset classes during the crisis, except for Bitcoin. Third, the war resulted in declining corporate security prices and increased asset volatility, potentially pushing asset values close to the default region. Finally, there were negative cumulative abnormal returns in global stock market indices, with varying effects across markets. More globalized economies were found to be more susceptible to international conflicts. The methods applied include a fixed-effect panel data regression model (Boungou and Yatié 2022), Univariate GARCH (Generalized

Autoregressive Conditional Heteroskedasticity) family models (Taera et al., 2023), a structural model for credit risk for high-frequency stock price data (Bougias,et al., 2022) and event study methodology (Boubaker et al., 2022). Furthermore, Kamal et al.'s 2023 study examined how the Australian stock market reacted to Russia's recognition of Donetsk and Luhansk regions as autonomous states. Initially, there were significant negative abnormal returns, particularly for small and medium-sized firms, as well as high-growth, illiquid, and export-oriented companies. However, these negative impacts diminished in the days following the event, suggesting that investors may have initially overreacted to political uncertainties. Beraich et al.'s 2022 study investigated volatility spillover effects in international financial markets before and during the Russian invasion. The study found that the volatility spillover index increased during the Russia-Ukraine war but remained lower than during the COVID-19 pandemic. Connectivity between American, European, and Chinese stock markets increased during the crisis, with the U.S. market having the highest volatility spread. The 2022 study by Izzeldin et al. (2022) offers a comprehensive analysis of the war's financial repercussions, comparing the invasion to other crises like the 2008 Global Financial Crisis (GFC) and the Covid-19 pandemic. Utilizing a Markov-switching HAR model to assess volatility, the research evaluates the duration and intensity for each event. The authors find an instantaneous market response to the invasion, which contrasts with the delayed reactions observed during the GFC and the Covid-19 pandemic. However, the study also observes that the global intensity of the financial impact from the Russia-Ukraine war is less severe than that of either the GFC or the Covid-19 pandemic. In addition to stock markets, the research also examines the impact of the war on various commodities, concluding that wheat and nickel were the most affected due to Russia and Ukraine's status as major exporters. Alam et al. (2022) employ a time-varying parameter vector autoregressive (TVP-VAR) approach to examine the effects of the Russia-Ukraine war on the dynamic relationships between various commodities and major

global stock markets and find a heightened level of interconnectedness among all commodity markets. The findings reveal that gold and silver, as well as the stock markets of the United States, Canada, China, and Brazil, primarily act as receptors of shocks transmitted by other commodities and markets during this crisis. On the other hand, platinum, natural gas, silver, and crude oil function as the main transmitters of these shocks.

This comprehensive body of research collectively highlights the effects of the war on agriculture and food security, energy markets, and other markets. While there are numerous studies on the effects of the war, 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 Black Sea Grain Initiative. This research contributes to the growing body of 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 global agricultural markets.

Modeling Framework

We employ the Global Trade Analysis Project (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; Hertel, 1997). 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 Appendix 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 Gross Domestic Product (GDP), following the literature (Hertel et al., 2010; Diffenbaugh et al., 2012; Boulanger et al., 2016; Beckman and Countryman, 2021). Data on population, investment and GDP were collected from the World Development Indicators database of the World Bank and from the International Monetary Fund (IMF).

Ukraine faced substantial export losses when ports were blocked by the Russian naval fleet for six months after the start of the Russian invasion, and about 20 million tons of grains 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. Two scenarios are modeled 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. Scenario I: 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 three months after the start of the full-scale invasion (March to May 2022). Scenario II: Strong ESL assumes full existing transshipment capacity, at the level observed through July 2023 after Russia exited from the BSGI but had not yet started attacking

the lower Danube River infrastructure, which is critical in the overall success of the ESL. Both scenarios model changes in agricultural exports conditioned on the export capacity of the ESL, keeping other factors fixed. We do not consider other impacts of the war such as further destruction of the Ukrainian agricultural sector and output. Scenario I: Weak ESL can be considered as a worst-case scenario while Scenario II: Strong ESL is a best-case scenario for agricultural exports from Ukraine with continued war.

Scenario I: Weak ESL assumes no exports through the BSGI routes, and that the ESL performance is limited to the transshipment volumes observed in March through May 2022, which is at most one million tons of agricultural exports per month, or approximately 20% of Ukraine's pre-war monthly exports. Scenario I: Weak ESL 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 one million tons per month at most compared to 2021 when export capacity functioned at full capacity. This an annualized extrapolation of the export flows through ESL observed in March through May 2022. Exports to all partner regions decreased substantially for all sectors except for grain exports 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 product exports to five out of eleven 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 Scenario I: 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 three months after the invasion. However, exports to Europe were lower than pre-war 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 domestically. Grain and 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%. Exports to the countries of the former Soviet Union have grown significantly. However, it is essential to note that in 2021, Ukraine's exports to these countries remained relatively low in absolute values. 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 of grains, other crops, wheat, vegetable oil, and processed food to MENA decrease by 87%, 56%, 98%, 68%, and 43%, respectively. However, oilseed exports to MENA more than doubled, wherein the demand from Turkey was a major driving force. Danube river exports and transit through the ESL reached MENA countries through Turkey as the key regional trader. Exports to other regions largely decreased. Despite the war, Ukraine still exported products to Russia and Belarus in Spring 2022, and we allow for minor export flows to both countries in this scenario.

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 MAPF 2023 data

Scenario II: Strong ESL assumes no transport from Ukraine through BSGI routes and that the ESL functions at its full technical capacity as was observed in 2022, before the Danube River transshipment capacity was constrained by the damages from Russian bombardments. Scenario II: Strong ESL 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 intuition for this scenario is the following. The ESL were used at their full transport capacity by Ukrainian exporters until July 2023, on top of the functioning BSGI 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 BSGI from total exports by commodity and country in the same year (MAPF 2023). The percentage changes are then calculated by comparing quantities exported from Ukraine through ESL by

commodity and destination region in 2022 compared to total exports by commodity and destination region in 2021.

As expected, total exports from Ukraine decline compared to pre-war levels, but are much larger in Scenario II than in Scenario I because of the larger export capacity through ESL when Black Sea ports are unavailable. 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 Scenario II exports to Europe increase for all commodity categories, but other crops: wheat exports increase by a dramatic 574% compared to 2021, while grains and oilseed exports also increase by 45% and 93%, respectively. Exports to former Soviet Union countries also increase, but from relatively low levels. Just as in Scenario I, the large relative increase in exports corresponds to relatively small trade volumes that are much lower than the export volumes to Europe and MENA. Remarkably, 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 of oilseeds, livestock and meat products, and vegetable oils to MENA increased by 179%, 2%, and 8% respectively. Exports of oilseeds to African countries increased by 43%, while vegetable oil exports decreased by 47%.

Table 2. Percentage changes of agricultural 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 MAPF 2023 data

Results

We simulate changes in wartime agricultural export flows from Ukraine given the dissolution of the BSGI and conditioned on the ESL performance. Results for both scenarios demonstrate net negative global impacts in terms of GDP and welfare. First, we describe the results for Scenario I, including simulated changes in aggregate exports, GDP, domestic production, and prices. Then we discuss the changes in simulated GDP and welfare outcomes in both scenarios and contrast the scenarios' 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 routes.

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. 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 for oilseeds. In the case of oilseeds, Ukraine increases seed exports instead of selling them for crushing in the domestic market. More details on this will be provided below when discussing changes in output. The largest increases in grain exports is simulated for FSU (23%), RUBE (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 South-East 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 RUBE occur in the absence of any trade policy restrictions imposed on exports from the region.

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

Sectors	Russia and Belarus	Former Soviet Union	Europe	Middle East North Agfrica	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 shows the simulated outcomes for percentage changes in GDP and domestic production for Scenario I: Weak ESL, where monthly agricultural export capacity does not exceed 1 million tons. 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, and a 15% decrease in oilseed output, and 10% decrease in production of other crops. While the reductions in production may appear substantial, it is important to note that this is primarily due to Ukraine's substantial export-oriented crop production. Export levels declined significantly, particularly for agricultural products, although oilseeds were less affected. 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 Rest of Asia and Oceania, 8% in the MENA region, and exceeding 7% in Europe. Wheat production also shows consistent simulated growth 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.

Table 4. Percentage Changes in GDP and Output across Regions and Sectors for Scenario I: Weak European Solidarity Lanes

	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
GDP, % change	**-10.06**	**-0.02**	**-0.08**	**-0.01**	**-0.07**	**-0.01**	**-0.01**	**-0.01**	**-0.03**	**0.00**	**0.00**	**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

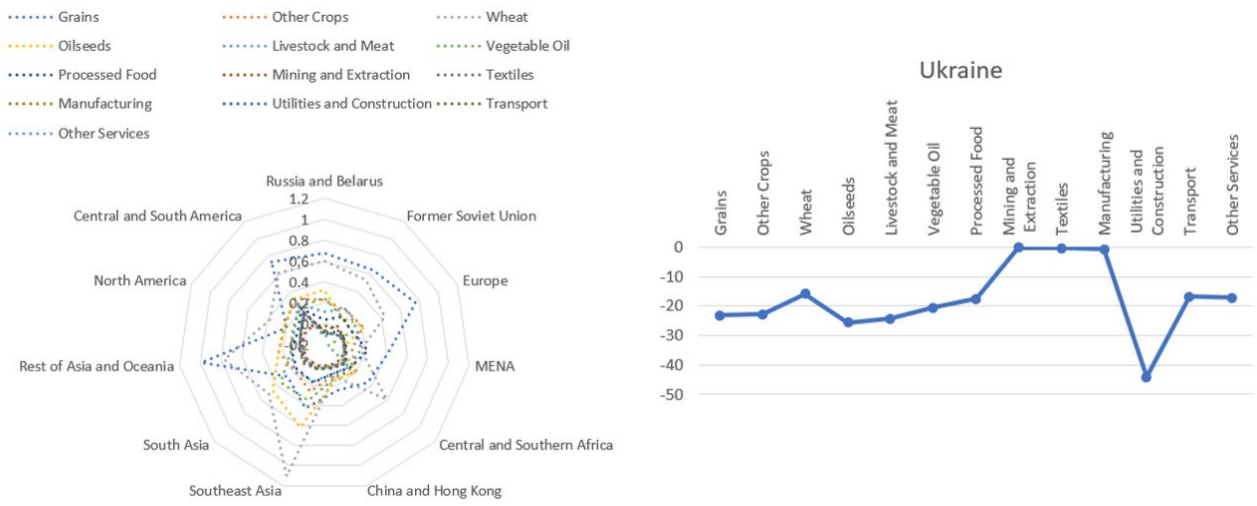
Source: Authors' presentation using simulation outcomes

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.

Figure 8 shows percentage changes in domestic prices across regions and sectors for Scenario I: Weak ESL. As expected, prices for agricultural products fall substantially in Ukraine when exports decrease. Price declines in Ukraine range from 16% and nearly 18% for wheat and processed food, respectively, to more than 20% for remaining sectors including vegetable oil, oilseeds, grains, other crops, and livestock and meat. Domestic prices increase by less than one

percent for all agricultural sectors across regions 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. The explanation is rather intuitive: Ukraine's exports are not fully replaced; therefore, agricultural production and prices are higher across regions outside Ukraine.

Figure 8. Percentage changes in Domestic Prices across Regions and Sectors for Scenario I: Weak European Solidarity Lanes



Source: Authors' presentation using simulation outcomes

Note: Changes in prices in Ukraine are considerably greater than in other regions and are indicated separately.

In summary, the findings of the Scenario I reveal that a reduction in agricultural exports from Ukraine to approximately 12 million tons per year, with the underperforming ESL, leads to a decrease in global GDP. The decline in GDP is accompanied by an uptick in domestic prices and the production of agricultural commodities in most other regions. In Scenario II: 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 Scenarios I and II. For Ukraine, GDP decreases by 10.06% in Scenario I, while GDP decreases by nearly 2% in Scenario II. Welfare in Ukraine is simulated to decrease by $17.6 billion in

Scenario I and by $4.5 billion in Scenario II. The GDP and welfare effects in Ukraine are driven by decreases in exports, domestic production, and domestic prices. RUBE, FSU, and MENA have less negative GDP effects in Scenario II, 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 (which excludes, Russia, Belarus, and Ukraine), Central and Southern Africa, South-East Asia, Rest of Asia, and the Americas gain welfare ranging from 3.39 million to nearly $1.03 billion in Scenario I. On the contrary, Europe (EU plus Balkan countries), 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 Scenario I. Simulated welfare losses for MENA are equal to nearly $1.1 billion in Scenario II, and is the most negatively affected region in both scenarios because it is the most dependent on agricultural exports from Ukraine. Interestingly, Europe simulated welfare decreases for Europe in Scenario I, and yet a simulated welfare gain of $1.9 billion was found in Scenario II. This is driven by a more efficient allocation of resources in production when the decrease in exports from Ukraine is less severe in Scenario II than in Scenario I. While five out of twelve regions have negative simulated welfare effects in Scenario I and eight regions have simulated negative welfare effects, global welfare is higher under Scenario II. Net global welfare is equal to more than $5 billion in Scenario II and nearly $20 billion in Scenario I.

Table 5. Percentage changes in GDP (%) and Welfare Changes (Million USD) in Scenarios I: Weak European Solidarity Lanes and Scenario II: Strong European Solidarity Lanes

Regions	Scenario I		Scenario II	
	GDP	Welfare	GDP	Welfare
Ukraine	-10.06	-17,613.86	-1.99	-4,599.08
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	1,905.76
Middle East North Africa	-0.07	-1,886.69	-0.03	-1,095.57
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	1,027.11	0.00	272.29

Source: Authors' presentation using simulations outcomes

Table 6 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 Scenario II because Ukraine can export more relative to Scenario I. Scenario II leads to lower simulated production levels than Scenario I for wheat, grains (mostly corn), oilseeds and vegetable oils in all regions except Ukraine. In Scenario I, the output of livestock, meat, and other crops is lower in most regions compared to Scenario II, except for Ukraine. Results are intuitive because Ukraine's export reductions are larger in Scenario I.

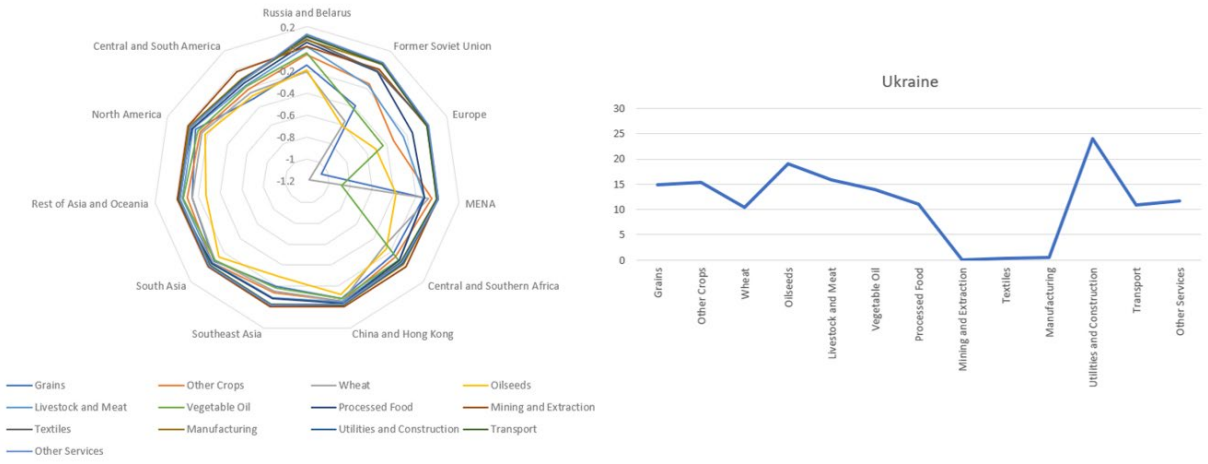
Table 6. Difference between domestic outputs between Scenario II: Strong European Solidarity Lanes and Scenario I: Weak European Solidarity Lanes

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

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

Figure 9 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 Scenario II. Domestic market prices for agricultural products in Ukraine are simulated to decrease by approximately 10 to 20 percentage points less in Scenario II compared to Scenario I. Furthermore, simulated domestic price increases in regions outside Ukraine are generally smaller in Scenario II 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 between the two scenarios.

Figure 9. Differences in domestic price changes across regions and sectors between Scenario I: Weak European Solidarity Lanes and Scenario II: Strong European Solidarity Lanes



Source: Authors' presentation using simulated outcomes

Note: 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.

Table 7 provides the percentage point differences between Scenarios II and I for simulated changes in aggregate exports by sector across regions. On a global scale, Scenario II yields relatively subdued impacts, primarily due to increased export capacity compared to Scenario I. We find lower export quantities for wheat, oilseeds, and vegetable oils across all modeled

regions, except for Ukraine for Scenario II compared to Scenario I. The magnitudes of the changes in exports vary across sectors. For wheat, output is less than 5 percentage points lower in Scenario II than Scenario I 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 Scenario II and Scenario I are similar for a given region and range from less than one percentage point to 7.5 percentage points lower in Scenario II than Scenario I. Additionally, grain sector exports, primarily comprising corn, are lower in Scenario II than Scenario I 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 Scenario I than in Scenario II across most regions, excluding Ukraine. Our findings align with intuition, given lower agricultural exports from Ukraine in Scenario I compared to Scenario II.

Table 7. 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

Discussion and 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 exacerbate price pressure (Baffes and 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 Least Developed 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 of agricultural exports from Ukraine.

This study simulates the repercussions of reduced agricultural exports from Ukraine due to the war, employing two distinct scenarios: one with weak ESL and another with strong ESL. The ESL Program, initiated by the EU in May 2022, was designed to create alternative transportation 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 non-agricultural 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 poses a significant challenge to 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.

This study simulates the GDP and welfare effects of war-induced decreases in agricultural exports from Ukraine under two scenarios. Scenario I: Weak ESL assumes limited ESL capacity that would allow up to 1 million tons per month, or 12 million tons per year, of agricultural product exports from Ukraine. Scenario II: Strong ESL assumes that total

agricultural exports from Ukraine are approximately 2.8 million tons per month, or 30 million tons per year. In both scenarios, agricultural production, domestic prices, and exports increase in most regions, except in Ukraine. GDP and welfare effects are negative or non-positive across regions, which indicates that the ESL is not able to compensate for missing agricultural exports from Ukraine that were available when transport was possible via the relatively cheaper Black Sea routes before the war.

There are three 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 post-war. As the ESL helps mitigate the adverse effects of the war, the critical role of a well-operating transportation infrastructure becomes apparent. In the post-war era, the full-scale operation of European Solidarity Lanes has the potential to boost trade between Ukraine and the EU, while also fostering the prospects for Ukraine's potential accession to the EU. As reopening of the Black Sea Grain Initiative remains questionable given Russia’s military and economic interests, the ESL provides support for Ukraine’s economy and people. Second, 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. This is useful for policy makers to consider when determining future domestic policy measures. 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. Further insight into the global, economywide effects of the war in Ukraine is warranted and relevant for policy makers around the world.

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Appendix

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
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
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
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
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 activi	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 defe	Other Services
edu	Education	Other Services
hht	Human health and social work a	Other Services
dwe	Dwellings	Other Services

Source: Authors' Aggregation of the GTAPv11 Database