Quantifying the impact of Russia–Ukraine crisis on food security and trade pattern: evidence from a structural general equilibrium trade model

Abstract

Purpose—Considering the importance of Russia and Ukraine in agriculture and the uncertain duration of their conflict, we designed two scenarios based on the assumption of a prolonged conflict (i.e., ending before July or ending October 2022, respectively), either of which would significantly impact the harvest of grains, and especially that of wheat.

Design/methodology/approach—After considering the most severe scenario – wherein Ukraine's production declines by 50%, trade from Ukraine is completely blocked, and Russia's trade is reduced by 50% using the Structural General Equilibrium Trade Model (SGETM) model – we proceeded to analyze the potential impacts of the conflict on the global agriculture market using the structural general equilibrium trade model.

Findings—Based on the multi-country and multi-sector model with different sector linkages, using counterfactual analyses, we found that the conflict would lead to soaring agricultural prices (10%-30%↑), and severe food insecurity with a decreased purchasing power for agricultural goods (15%-25%↓), especially for those countries that rely heavily on grain imports from Ukraine and Russia, such as Egypt and Turkey. However, major production countries such as the United States, Canada, and Australia may even benefit from the conflict. Restrictions on upstream trade flows of energy and fertilizer will amplify the negative effects of food insecurity given Russia's importance in the worldwide market for these products. Meanwhile, restrictions over downstream trade flows for manufacturing sectors are expected to have only negligible effects.

Originality – We analyzed the effect of Russia-Ukraine conflict on global food security based on sector linkages under the general equilibrium framework.

Key words Russia-Ukraine conflict, food security, agriculture commodity price, agriculture trade, welfare

Paper type Research paper

JEL Classification: F17, Q17

1 Introduction

It is well known that Russia and Ukraine play leading roles as global suppliers of food, fertilizer and energy. For example, in 2020 the two countries represented worldwide 53 percent of sunflower oil and seeds, 27 percent of wheat, 23 percent of barley and 13 percent of corn (UNCTAD, 2022). As for the fertilizer market, which is part of the upstream market for the agricultural sector, as the world's largest exporter of fertilizers, Russia accounts respectively for 23, 21, 14 and 10 percent of ammonia, potash, urea and processed phosphate exports worldwide. Meanwhile, agriculture production itself requires substantial amounts of energy either directly or indirectly through the consumption of fuel, gas and electricity. The compositions of fertilizers, pesticides and lubricants are also largely comprised of and therefore dependent on fossil fuel energy inputs. Russia is also a key player in the energy sector, accounting for 11 and 10 percent of global oil and gas exports.[1]

On February 24, 2022, the Russian-Ukrainian conflict broke out. Subsequently, the global supply of agricultural commodities dropped precipitously,[2] with the world's food security having become threatened in various ways, including creating challenges for production, costs and international trade. First, the Russian-Ukrainian conflict caused major damage to productive assets, agricultural land, labor availability, roads and other civilian infrastructure, with farmers being unable to attend to their fields or engage in harvesting. Hence, much uncertainty as to expected wheat, maize and rapeseed crop yields has arisen as the farming season takes hold in Ukraine. Second, grain exports from Russia, Ukraine and other neighboring countries are at risk of being canceled or delayed with the ongoing disruptions to Black Sea ports (FAO, 2022). Third, food export restrictions have further reduced the global food supply. Since the Russia-Ukraine conflict on Feb. 24, 16 countries imposed export restrictions on food (as of early April 2022), including Indonesia (ban on palm oil exports), Argentina (ban on beef exports), and Turkey, Kyrgyzstan, and Kazakhstan (bans on a variety of grain products).[3] Fourth, while the conflict has directly exacerbated international food prices, it has also led to rises in the prices of fertilizer and energy, which has indirectly increased

[1] https://www.tfi.org/content/statement-russia-ukraine-conflict
[2] Ukraine provided 13% of the world's maize and 9% of its maize in 2020. More than 95% of these agricultural foodstuffs were shipped out of the country for export via the Black Sea, However, that vital conduit is now being blockaded, choking off Ukraine's maritime trade after its ports came under attack from Russia's military, which has consequently led to a significant decrease in the worldwide grain supply.
[3] https://www.foodsecurityportal.org/node/1963

the cost of growing food.[4] Since the beginning of 2022, there have been 47 countries imposing export restrictions on food and fertilizers, 43 of which have been put in place since the Russia-Ukraine conflict.[5]

Since Ukraine and Russia play an important role in the global food and fertilizer market, the conflict between them would lead to a global food supply shortage and put much pressure on food prices. This food security crisis caused by the Russia-Ukraine conflict will seriously impact poor developing countries, particularly those highly dependent on Russian and Ukrainian agricultural exports. Take Africa for example, during the period from 2018 to 2020, countries on the continent imported $3.7 billion in wheat (32 percent of total African wheat imports) from the Russian Federation and another $1.4 billion from Ukraine (12 percent of total African wheat imports) (UNCTAD, 2022). These figures suggest that if the conflict undermines agricultural production and trade activity in Ukraine and Russia, it will lead to a severe impact on the grain trade. Therefore, it is important to quantitatively evaluate the effect of the conflict on food production, trade and national welfare for different countries in a multifaceted and targeted manner.

Based on the scenario described above, we use the structural general equilibrium trade model and data from the Global Trade Analysis Project (GTAP) database to quantify the effects of the Ukraine-Russia conflict. Our results show that developing countries, especially those that rely on grain imports from Ukraine and Russia, are likely to be significantly impacted by the conflict. The conflict has lasted for more than two months and we still cannot see the end in the near future. Considering the uncertainty regarding the conflict's duration, we designed two scenarios according to the assumption of a prolonged conflict (i.e., ending before July or October 2022, respectively), either of which would significantly impact the harvest of grain, and especially that of wheat. According to estimates from FAO and considering the most severe scenario – wherein Ukraine production declines by 50%, trade from Ukraine is completely blocked and Russia's trade is reduced by 50% – we proceeded to analyze the potential impacts of the conflict on the global agriculture

[4] The conflict and resultant sanctions have led to a reduction in oil and gas exports from Russia, boosting petroleum prices while generating rises in agricultural machinery and international food prices, leading to a contraction in global grain supplies. At 10:58 a.m. CDT (1558 GMT) on March 25, 2022, the Chicago Board of Trade's (CBOT) May soy-bean futures SK2 were up 6 cents at 17.06-3/4 dollars a bushel. Meanwhile, the CBOT's May corn CK2 was 4-1/2 cents higher at 7.52-3/4 dollars a bushel and CBOT's May wheat WK2 was up 4-1/4 cents at 10.90 dollars a bushel. Wheat, corn, and soybean futures have generally continued to rise, intensifying the food security crisis.

[5] https://bdnews24.com/world/2022/04/30/governments-tighten-grip-on-global-food-stocks-sending-prices-higher

market using the structural general equilibrium trade model. Our model features real-world mechanisms that could affect the global wheat market. As the conflict can spread to the world and affect all sectors through global trade. We include 51 countries and a constructed rest of the world [6] as well as 33 sectors[7] in the model. In our model, the output from one sector can be used for final consumption or as intermediate input for other sectors. In this way, a drop of wheat productivity in Ukraine can directly affect the final consumption for each country and global wheat production through the IO linkage. Moreover, productivity varies depending on countries and sectors, which could react differently to the Russia-Ukraine conflict. In addition, we also introduce trade barriers, which allows us to investigate the effect of trade disruption given that the Black Sea trade route, through which over 98% of Ukraine's crop is exported, has been blocked since the conflict outbreak. Based on the above assumptions, we found that the conflict would lead to soaring agricultural prices, and severe food insecurity with a decreased purchasing power for agricultural goods, especially for those countries that rely heavily rely on grain imports from Ukraine and Russia, such as Egypt and Turkey, with domestic price increases of about 30% and overall welfare dropping by around 25%. However, countries such as the U.S., Canada, and Australia may even benefit from the conflict as major producers of grains. Restrictions on upstream trade flows of energy and fertilizer will serve to amplify the negative effects of food insecurity given Russia's importance in the worldwide market for these products. Meanwhile, restrictions over downstream trade flows for manufacturing sectors are expected to have only negligible effects.

Our paper contributes to the relevant literature in the following two aspects. First, a growing literature has recently started to examine the food security effects of the Russian-Ukrainian conflict. Existing contributions have focused primarily on the price effects or limited areas (FAO, 2022; WTO, 2022). Meanwhile, Fellmann, Hélaine, and Nekhay (2014) studied the impact of grain harvest failure and export restrictions (bans, quotas, and taxes) on food security using the Aglink-Cosimo model, a partial equilibrium model. They found that limited grain exports fueled agricultural price increasing. Besides, export restrictions negatively affect import and export countries, like aggravating world grain markets and decreasing domestic consumer prices to the normal level. In addition,

[6] Please see Table A1. in the appendix for the detailed country list.
[7] Detailed information is listed in the last paragraph in Section 2.2.

Felbermayr et al.(2022) found that trade barriers almost shut down bilateral trade and decrease welfare in all countries involved. Besides, Rutten, Shutes, and Meijerink (2013) showed that free trade mitigated rising prices in the wheat market and contributed to food security significantly. Moreover, Balma et al. (2022) found that comparing with other cereals, the negative effect is almost entirely concentrated on wheat imports, where Egypt and South Arica decreased by 48.2% and 40.7% of their wheat import respectively. In addition, countries like Kenya and Rwanda experienced 32.4% and 29.6% higher wheat prices. Martin-Shields and Stojetz (2019) found that food price volatility and prevalence of undernourishment are related to conflict-affected areas. Nillesen (2016) showed that exposure to individual violence decreases the probability of growing coffee by 16%. Apart from prices or food security, scholars also investigate the effect of conflicts on other social indicators like children's development. Bundervoet et al.(2009) found that an additional month of war exposure decreases children's height for age z-scores by 0.047 standard deviations. Compared with unexposed girls of the same cohort, war-exposed girls suffered a reduction in an adult height of 0.75 centimeters. Akbulut (2014) found that individuals suffered 0.6 inches shorter on average in adulthood because of conflicts. Our paper shows a similar conclusion to the above analysis, which also presents the reliability of the conclusion.

On the other hand, our paper departs from existing studies in several key aspects. First, our structural general equilibrium trade model complements the previous models investigating the effects of Russia-Ukraine conflict on food security. Compared with the Aglink-Cosimo model, our general equilibrium analysis can provide a more integrated picture of the impacts of the conflict on food output, trade, prices and welfare. In contrast to GTAP models, our quantified structural model permits a clearer demonstration of the influence mechanism based on fewer parameters. Second, in a departure from previous studies, apart from agricultural exports and grain supplies, we also considered the input-output linkage to study the impact of the conflict on upstream agricultural sectors, such as fertilizers, gas and crude oil, as well as downstream sectors, such as food processing industries. Third, besides food production, trade, and prices, we studied how real wages, which is a measure of purchasing power and can be used to evaluate the country's overall welfare, changes during the conflict. Fourth, we study the impact on every country in the world instead of only selecting limited areas.

Furthermore, there is also a large literature that examines food security based on other factors such as subsidies, climate change, storage conditions, and export restrictions. Yi, Sun and Zhou (2015) and Wright and Cafiero (2011) found that subsidies are productive for increasing cultivation areas and maintaining grain reserves. In terms of climate, Devereux (2007) and Guo *et al.* (2019) found that natural disasters, such as droughts and floods, have had a severe impact on food security in Malawi and China. Kumar and Kalita (2017), Gitonga *et al.* (2013), Zachary *et al.* (2015), Manandhar, Milindi and Shah (2018) argued that improved storage conditions are beneficial for food security in developing countries. Besides, export restrictions are also cited as a key factor for food security (Götz, Glauben and Brümmer, 2013; Svanidze *et al.*, 2019) and Ogundari (2014) believes that education, experience, and credit are the main drivers for agricultural efficiency.

The remainder of this paper is structured as follows: In Section 2, we present our modelling framework and data. Following that, in Section 3, we introduce our settings, scenarios and calibration procedures. Section 4 then presents the results of our analysis on price, trade, output and welfare effects arising from the Russia-Ukraine conflict under different scenarios. Finally, we detail our concluding discussion in Section 5.

2 Modeling framework and related data

In this section we develop a quantitative general equilibrium model to quantify the effects of the Ukraine-Russia conflict. The model is built on Caliendo and Parro (2015) and incorporates productivity differences, trade in intermediate goods, input-output linkages, and trade barriers. Several studies are being conducted to examine how stochastic shocks (e.g., extreme weather events, COVID-19) at one node in a supply chain can affect several other agents in a supply chain, such as Zilberman et al. (2022), Lu et al. (2021) and Baqaee and Farhi (2020). In this article, we have considered different sectoral interactions based on input-output tables, matching real-world trade with gross output precisely and predicting counterfactual outcomes. Then, we answer several 'what if' questions, such as what would happen to the global agricultural commodity prices, trade and welfare if the conflict lowers Ukraine's agricultural productivity and blocks trade flows, and what will happen if some large agricultural producers attempt to increase their production as a remedy.

2.1 Model setup

There are *n* countries and *j* sectors, as well as one factor of production (labor) in the economy. Within each country-sector combination there is a market. Each market has a continuum of perfectly competitive firms producing intermediate goods. There is a final goods producer that uses only intermediate goods and produces non-tradable final goods. The intermediate goods are freely tradable and only used to produce final goods. Final goods are consumed locally or used as intermediate inputs for intermediate goods producers. After describing the economy's parameters, we solve for the supply and demand of this economy and close the model using market clearing conditions.

1) *Consumer problem*

In each country *n*, there are a fixed number L_n of consumers maximizing the following Cobb–Douglas utility by choosing each of the consumption goods:

$$U(C_n) = \prod_{j=1}^{J} C_n^{j\,s_n^j}. \quad (1)$$

Where C_n^j is the consumption of final good *j* in country *n*, s_n^j is the share of expenditure spent on C_n^j. The share of expenditure s_n^j sums up to 1. Each consumer supplies a unit of labor inelastically. The only income comes from wages and there are no other expenditures. Solving for this maximizing problem yields the demand for each final good in each country.

2) *Final goods production*

In each country-sector market (n, j), there is a final goods producer. The production of final goods Q_n^j uses each of the intermediate goods ω^j sourced from the lowest cost suppliers available across countries. Final goods are used either by local consumers in final consumption or by local intermediate goods producer as inputs. The production technology for Q_n^j takes the form of the constant elasticity of substitution (CES):

$$Q_n^j = \left[\int r_n^j\left(\omega^j\right)^{\frac{\sigma^j-1}{\sigma^j}} d\omega^j\right]^{\frac{\sigma^j}{\sigma^j-1}} \quad (2)$$

Where $r_n^j\left(\omega^j\right)$ denotes the demand for intermediate goods ω^j sourced from the lowest cost supplier.

3) *Intermediate goods*

In each country-sector market (n, j), there is a continuum of perfectly competitive intermediate goods producers. Each intermediate good is produced using labor and materials from all sectors as inputs. Production technology takes the form of the Cobb–Douglas function:

$$q_n^j(\omega^j) = z_n^j(\omega^j)\left[A_n^j(\omega^j)l_n^j(\omega^j)\right]^{\gamma_{l,n}^j} \prod_{h=1}^{J}\left[m_n^{h,j}(\omega^j)\right]^{\gamma_n^{h,j}} \quad (3)$$

Where $z_n^j(\omega^j)$ is the overall efficiency of producing intermediate goods ω^j, $A_n^j(\omega^j)$ is the labor specific productivity, $m_n^{h,j}(\omega^j)$ is the material in sector *h* used by intermediate goods producer ω^j, and $l_n^j(\omega^j)$ is the labor employed for production. Parameters $\gamma_{l,n}^j$ and $\gamma_n^{h,j}$ indicate the share of labor compensation and share of material input costs in relation to total output. We assume $\gamma_{l,n}^j + \sum_{h=1}^{J}\gamma_n^{h,j} = 1$, so that the production function has a constant return to scale. Under a perfect competitive market, this implies zero profit, with the utility maximization yielding the unit cost:

$$c_n^j = \mu^j (w_n)^{\gamma_{l,n}^j} \prod_{h=1}^{J}(P_n^h)^{\gamma_n^{h,j}}. \quad (4)$$

Where $\mu^j = (\gamma_{l,n}^j)^{-\gamma_{l,n}^j} \prod_{h=1}^{J}\left(\gamma_n^{h,j}\right)^{-\gamma_n^{h,j}}$ is a constant, w_n is the wage in country *n* and P_n^h is the price of material *h* in country *n*.

4) *Trade*

Trade is costly and takes the form of an iceberg cost in the model. For each unit of intermediate goods in sector *j* shipped from country *i* to country *n*, $d_{ni}^j > 1$ unit of goods is required for production. This means that $d_{ni}^j - 1$ unit of goods is lost in the process of transportation. Following Eaton and Kortum (2002), we assume that $z_i^j(\omega^j)$ follows the Fréchet distribution. Thus, the bilateral trade share can be expressed as following:

$$\pi_{ni}^j = \frac{\left(A_n^j\right)^{\theta^j \gamma_{l,i}^j}\left(d_{ni}^j c_i^j\right)^{-\theta^j}}{\Phi_n^j} \quad (5)$$

Where $\Phi_n^j = \sum_{f=1}^{N}\left(A_n^j\right)^{\theta^j \gamma_{l,i}^j}\left(d_{nf}^j c_f^j\right)^{-\theta^j}$, π_{ni}^j is the share of expenditure on good *j* from country *n* by country *i*.

5) *Market clearance*

To complete the model, both the goods market and labor market must be cleared, while trade is in balance. To solve the model and perform our counterfactual analysis, we exploit the "exact hat" algebra approach to express all equilibrium conditions in changes, *i.e.*, $\hat{x} = \frac{x'}{x}$ is the relative change of the variable in different scenarios. The final equilibrium can be expressed in alignment with the following conditions:

$$\hat{c}_n^j = (\hat{w}_n)^{\gamma_{l,n}^j} \prod_{h=1}^J \left(\hat{P}_n^h\right)^{\gamma_n^{h,j}} ; \tag{6}$$

$$\hat{P}_n^j = \left[\sum_{i=1}^N \pi_{ni}^j \left(\hat{d}_{ni}^j \hat{c}_i^j\right)^{-\theta^j} \left(\hat{A}_n^j\right)^{\theta^j \gamma_{l,i}^j}\right]^{-\frac{1}{\theta^j}} ; \tag{7}$$

$$\hat{\pi}_{ni}^j = \left[\frac{\hat{\kappa}_{ni}^j \hat{c}_i^j}{\hat{P}_n^j}\right]^{-\theta^j} \left(\hat{A}_n^j\right)^{\theta^j \gamma_{l,i}^j}; \tag{8}$$

$$X_n^{j'} = \sum_{h=1}^J \gamma_n^{j,h} \sum_{i=1}^N \frac{\pi_i^{h'}}{1+\tau_{in}^{h'}} X_i^{h'} + s_n^j I_n'; \tag{9}$$

$$\hat{w}_n w_n L_n = \sum_{j=1}^J \gamma_{l,n}^j \sum_{i=1}^N \frac{\pi_{in}^{j'}}{1+\tau_{in}^{h'}} X_i^{j'} , \tag{10}$$

Where $I_n' = \hat{w}_n w_n L_n + \sum_{j=1}^J \sum_{i=1}^N \tau_{n_i}^{j\ '} \frac{\pi_{ni}^{j'}}{1+\tau_{in}^{h'}} X_n^{j'} + D_n{}'$. This is a set of N*J + N*J + N*J*N + N*J + N non-linear equations. Based on these conditions, we solved the model using Matlab according to the algorithm proposed by Caliendo and Parro (2015).

With these features in the model, we apply the exact hat algebra and the algorithm proposed by Caliendo and Parro (2015) to match the data to the model. We were able to match real-world trade and gross output precisely without solving the fundamentals explicitly. Then we were able to carry out our counterfactual analysis, *i.e.*, what will agriculture prices and gross output be after the conflict as compared with a world where such a conflict did not occur.

2.2 Data

Trade between countries and across sectors are the key determinants of global agriculture commodity price. The agriculture commodity prices will encompass the entire worldwide market and affect all sectors through global trade. We have included 51 countries in addition to a constructed "rest of the world" in our model. The rest of the world was constructed based on data availability and country size. It includes any country that is either too small or does not provide any individual trade or production data. Countries were selected on the bases of their reliance on Ukraine and Russia agricultural exports. We have included the top 20 countries that import the largest shares of wheat from Ukraine and also the major economies of the world (see Table A1. in the appendix for the detailed country list).

We have included 11 agriculture sectors, 13 upstream sectors, 7 downstream sectors and 2 service sectors in the model. All 33 sectors are as follows: paddy rice, wheat, other cereal grains, vegetables, fruits and nuts, oil seeds, sugar, plant-based fibers, other crops, meat products, forestry, fishing, crude oil, gas, coal, other minerals, vegetable oils and fats, processed food, textiles and clothing, leather, wood, paper, mineral products, medical products, metal products, computer and electronic products, equipment, transport equipment, other manufactured goods, electricity, natural gas, transportation and communications, and other services.

3 Settings, scenarios and calibration procedures

3.1 Settings and scenarios

In this section, we quantitatively evaluate the effects of the conflict on the agriculture trade, price levels and welfare for each country. Since the theatre of the conflict is within Ukraine's borders, Ukraine's agricultural production will therefore be disrupted. Furthermore, the trade between Ukraine and Russia with the rest of the world will also be affected as a result of the blockade of Black Sea ports. Thus, the conflict primarily affects the world's food security in two ways:

1) by decreasing Ukraine's agricultural productivity;

2) by disrupting trade between Ukraine and Russia with the rest of the world.

We hence consider two cases showing how Ukraine's agricultural productivity may be affected according to the scenario of a prolonged conflict based on the FAO's winter wheat estimates.[8]

1) In the first case, the conflict continues until September, which is the current situation. Due to the data limitation, we assume that wheat productivity decreases by 43% based on the number from Ukraine's grain trader's union. The union claimed in July that Ukraine could harvest 20.8 million tons, a 25% decline in productivity. We assume that the productivity drops at the same speed until September, i.e., a 43% decline in productivity so far.
2) In the second case, if the conflict was to finish during the snowfall season for winter wheat (late October), the autumn sowing for the 2022-2023 farming season would also be negatively

[8] See FAO, Information Note, "The importance of Ukraine and the Russian Federation for global agricultural markets and the risks associated with the current conflict," Food and Agriculture Organization of the United Nations, http://www.fao.org/3/cb9236en/cb9236en.pdf.

impacted, with production only amounting to 13 million tons. Hence, we assume that productivity declines by 50% in this case.

To gain insights on the contribution of different sectors and especially input-output linkages, we pose questions as to how the upstream energy sector affects food security and how the food sector affects downstream food production. To this end, we take three different scenarios about trade disruption into account as follows:

1) In the first scenario, we only consider a blockade of the agricultural trade and investigate the direct effects of a disruption to agricultural exports.

2) In the second scenario, and apart from the agricultural trade, we also consider a trade disruption to Ukraine and Russia's upstream sectors, such as crude oil, natural gas, and fertilizers.

3) In the last scenario, we further include trade destruction in the downstream sectors, such as veg and oil processing, production of food. We also consider cases either only Ukraine trade or both Ukraine and Russia trade contracts. We summarize our channels and scenarios as following Table 1:

Table 1: Conflict-led channels and various scenarios

3.2 Calibration

Detailed procedures for our settings and scenarios are as follows. First, we compute the baseline economy which exactly matches the pre-conflict trade and gross output for all sectors and countries. Then, we calculate the counterfactual economy that satisfies all equilibrium conditions as indicated in equations (6) – (10) (*i.e.*, rational consumers maximize utility at given prices and income by buying food from the cheapest sources; firms maximize profits and volumes of goods; along with factor market clearance), applying the model based on our assumptions that the conflict will lead to a reduction in Ukraine's overall agricultural production as well as trade disruptions for both Ukraine and Russia. We moreover adjust the shock effects to investigate several scenarios. For example, a situation where productivity either decreases by a small number or a large number, as well as a situation where Russia's trade is either affected or not. Thereafter, with the equilibrium calculated in the counterfactual economy, we can infer the changes in welfare in each country that are caused by the conflict by comparing the counterfactual economy with the baseline economy.

To calibrate the model, we needed to determine the bilateral trade value, gross output, value added and input-output coefficient for each country and sector. All such data can be sourced from the Global Trade Analysis Project (GTAP). GTAP is a global database describing bilateral trade patterns, production, consumption and the intermediate use of commodities and services. With these data points at hand, we were then able to calibrate consumption share parameters and input share parameters in the utility function and the production function. The trade elasticities have been derived from Caliendo and Parro (2015). Together with these parameters and initial values, we could solve for prices and welfare using market clearing conditions – that is, consumption equals output for each country-sector market, labor demand equals labor supply, and trade is balanced.

Several features of our model enabled us to study a wide range of counterfactuals. First, sector differences in our model allowed us to investigate the effects of Ukraine's declining production. Since the conflict has taken place within Ukrainian territory, the country's production has been disrupted and hence has faced a decline in productivity. Moreover, one sector's output can be used not only as final consumption, but also as an intermediate input for other sectors. Our model with input-output linkages is useful for capturing this effect. Given the shock to the country, Ukraine's shrinking agricultural productivity in our model for instance will not only affect final consumption for each country, but also influence global agricultural production directly through input-output linkages. Meanwhile, trade across countries for different sectors can vary in our model. This allows us to investigate the effects of only Ukraine's agriculture commodity trade disruption while keeping all other countries and sectors' trade costs unchanged, since the conflict mainly restricts the trade route through the Black Sea, which accounts for more than 98% of Ukraine's grain exports. With the sector-country specific trade cost in the model, we can also study the contribution of trade in each sector by adjusting trade costs only for certain sectors, such as upstream sectors and downstream sectors.

4 Results

We first assume that the conflict only causes a disruption to Ukraine's agricultural production and trade. Figures 1a and 1b show the welfare changes and agriculture price changes when Ukraine's trade is fully blocked (100% trade destruction) or half blocked (50% trade destruction). Under the same level of trade destruction, the welfare or price level effects of productivity decrease, i.e., either decrease by 38% or 50%, and are almost identical. This is because when productivity decreases from 62% to 50%, other countries' import share only changes slightly (see Figure A1 in the appendix), which only has a minimal effect on their welfare. However, when trade destruction increases from 50% to 100%, the agricultural import share for many countries will decrease by an additional 10%-25%, which thus generates larger negative effects. Therefore, welfare losses are mainly caused by trade destruction and rising prices.

On average, welfare losses double for the fully blocked case compared with the half-blocked case. The most affected countries are certainly those that rely heavily on grain imports from Ukraine (see Table A1 in the appendix for wheat as an example). The top ten most affected countries (Egypt, Iran, Spain, Morocco, Pakistan, Turkey, Georgia, South Africa, Israel, Tunisia) suffer from a 4% welfare loss (with a 4% price increase) on average under the half-blocked case and an 8% loss (with an 8% price increase) under the fully blocked case. Ukraine is also expected to see a 12% decrease in its welfare, second only to Egypt, one of the world's largest wheat importers and 60% of whose imports come from Ukraine and Russia. It is also notable that some countries can even gain from the conflict, such as Canada, Australia, and the U.S. These countries are large agricultural exporters and gain from improvements in the terms of trade through global agricultural price increases and higher export demand in the global market (see Figure A2 in the appendix).[9]

Fig 1a. Agriculture effect on welfare with only Ukraine trade block

Fig 1b. Agriculture effect on price with only Ukraine trade block

Next, we further modify our scenario to assume that the conflict causes a disruption to both Ukraine's and Russia's agricultural exports. As a result of the conflict, Russia is expected to see a reduction in some exports. To protect the domestic grain supply from and the constraints of the West after the conflict was initiated, Russia instituted a temporary ban on the export of wheat, mixed wheat, rye, barley and corn to Eurasian Economic Union member states and the export of white sugar and sucrose to third countries.[10] Meanwhile, in response to the trade sanctions imposed on Russia by European Union member states and the U.S., among other countries, which targeted oil,

[9] In figure A3 in the appendix, we also show the map about the effects of scenarios that Ukraine production declines by 15%, 38% and 50% and trade is fully blocked in Ukraine on trade, price and welfare in the world economies.
[10] https://topic.echemi.com/a/russian-prime-minister-signs-decree-temporarily-banning-grain-exports-to-eurasian-economic-union-member-states_219799.html

gas and fish exports, Russia's trade and industry ministry recommended that the country's fertilizer producers temporarily halt exports.[11] Since differences in productivity declines only have negligible effects, hereafter with the assumption of a disruption to Russia's trade, we assume that Ukraine's productivity decreases by 50%. Figures 2a and 2b show the welfare changes and price changes when Ukraine's trade is fully blocked (100% trade destruction) or half blocked (50% trade destruction) while Russia's trade is blocked by 10% or 50% (Lacina *et al.*, 2022). In this situation, the welfare losses become larger compared with the case when Russia's trade is not affected. For most countries, when Russia's trade destruction rises from 10% to 50% it leads to a two to three-fold rise in welfare losses and price increases. For the most affected countries, welfare losses amount to 15%-25% (with 10%-30% price increases). Meanwhile, one finds that Canada, the U.S. and Australia can still gain in this case as major producers.

Fig 2a. Agriculture effect on welfare with both Ukraine and Russia trade block

Fig 2b. Agriculture effect on price with both Ukraine and Russia trade block

In addition, we take upstream sectors into account to take a closer look at the food security challenge created by the conflict. Apart from the disruption to the agricultural trade, we assume that the trade in crude oil, natural gas and fertilizers are also blocked. Figure 3a shows that the welfare losses nearly double compared with Figure 1a. Welfare decreases by another 15%-25% for the most affected countries when Russia's trade destruction rises to 50%. Similarly, average agricultural prices are about 15% higher than in Figure 1b. These large welfare losses are caused by Russia's resource trade destruction through input-output linkages, which increases the raw material input prices for downstream sectors. These results emphasis the importance of the resource trade and its role for agricultural production networks and food security.

Fig 3a. Resource effect on welfare with both Ukraine and Russia trade block

Fig 3b. Resource effect on price with both Ukraine and Russia trade block

[11] https://www.agweb.com/news/policy/politics/russian-ministry-recommends-fertilizer-producers-halt-exports

Finally, we consider the situation where there is trade destruction to downstream sectors, *e.g.*, food manufacturing sectors. Figure 4 (a, b) shows the welfare and price effects under this circumstance. Welfare losses and price changes for all countries are similar to the case where downstream sectors are not blocked (see Figure 3 (a, b)), except that Ukraine sees roughly a 4% higher loss in this case. On the one hand, downstream sectors are closely connected with final consumption and therefore have smaller effects on food security (i.e., food prices and welfare) through input-output linkages than upstream sectors such as energy and fertilizer. On the other hand, Ukraine and Russia are not major exporters in the food manufacturing sector. Other countries can easily find substitutes and mitigate losses when the trade in food manufacturing goods is blocked from Ukraine and Russia.

Fig 4a. Food manufacturing effect on welfare with both Ukraine and Russia trade block

Fig 4b. Food manufacturing effect on welfare with both Ukraine and Russia trade block

5 Concluding discussion and policy suggestions

In this paper, we considered different scenarios based on the duration of the Russia-Ukraine conflict and trade disruptions to both Ukraine and Russia in terms of agricultural, energy and downstream manufactured goods to quantify the potential welfare effects on the global market arising after the initiation of the conflict. If we only consider the case where Ukraine production declines by 50% and its trade is completely blocked, we find that the conflict would lead to a significant increase in global agriculture prices and a decrease in welfare for most countries. Specifically, increases in agriculture prices are estimated to reach 3%~18% in those countries that rely on grain imports from Ukraine. This is mainly driven by a decline in imports (*i.e.*, an 8%~22% reduction) for worldwide trade, resulting in a significant drop in welfare (*i.e.*, a 6%~16% reduction). If further adding a 50% trade disruption to Russia, the conflict would lead to soaring agricultural prices (rising by 10%-30%), and severe food insecurity with a decreased purchasing power for agricultural goods (falling by 15%-25%). Restricting upstream sector trade amplifies the negative effects and decreases welfare for those relatively poorer developing countries that heavily rely on grain imports from Ukraine and Russia, such as Egypt and Turkey, which falls by another 15%-25% despite downstream sectors only showing negligible effects. According to the Chicago Board of Trade, wheat prices rose by 22%, 8%, and 18% year-over-year between July and September 2022, which is more in line with the results of our study (10%-30% increase in agricultural prices). In terms of trade, based on UNComtrade, we found that wheat imports from Pakistan, Egypt, and Uzbekistan declined by 37%, 18.33%, and 18.29% after the outbreak of war (from March to August 2022). Moreover, compared to March-August 2021, the imports of agricultural products such as cereals, flour and oil crops [12] were also decreased by 11.8% and 27.6% in Georgia and Turkey respectively. This is not much different from this paper's conclusion (15%-25% decrease in purchasing power). However, countries such as the U.S., Canada, and Australia could even stand to benefit from the conflict as major producers.

In addition to the conflict itself, there are other potential risks that are threatening global food security and welfare, such as ad hoc policy measures that include export restrictions, climate-induced risks, COVID-19 and speculation in the agricultural market, which may further exacerbate the situation to become worse. For example, on the evening of May 13, the Indian government announced an immediate ban on wheat export although the paper predict that India should expand their wheat exports due to India is the second largest wheat exporter in the world. Therefore, there is an urgent need for an international policy dialogue and improved global governance since we believe that these approaches can play critical roles to ensure that international markets continue to function normally and trade flows smoothly. Still take India for example, India's temporary ban on wheat exports was condemned by the G7 agriculture minister. As a consequence, in order to overcome restrictions on grain exports, those countries that heavily rely on Ukraine and Russia grain exports should promote import diversification while reducing trade costs to better ensure their food security.

Our modeled counterfactual results show that countries such as the U.S., Canada, and Australia may even benefit from the conflict by increasing their exports and production volumes. However, this is a simplified response to increasing food prices across different countries, while the restoration of the global food market (i.e., back towards the price equilibrium established before the conflict) depends on actual supplies of food in these countries. To alleviate the global food crises, farmers in major production countries need to increase their outputs and exports. In practice, these farmers may have limited information on when the war would end and overreact or underreact to the crises.

[12] Their 2-aggregated HS commodity code are 10, 11 and 12 respectively.

Therefore, policy makers in these countries should help farmers make correct decisions using proper policies. Some practical policy measures would be to subsidize agricultural inputs, increase the land supply, and lower land rental prices, several of which have been adopted in countries around the world. Hence, we strongly suggest that major agricultural producers, such as the U.S., Canada, France, Brazil, Germany, etc., move to increase their production and export volumes in order to alleviate the current global food crisis.

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