Online Material: Russian Invasion of Ukraine, Food Security, and Climate Change

August 11, 2022

Contents

1 Agricultural Trade from Russia and Ukraine

Russia and Ukraine are major exporters of wheat and maize. For 2017-2021, total wheat exports as a share of total global exports were 21.4% and 9.3% for Russia and Ukraine, respectively (USDA, 2022). The share of both countries is smaller for maize exports, i.e., 2.5% (Russia) and 14.5% (Ukraine). The export share for other commodities is depicted in Figure S1.

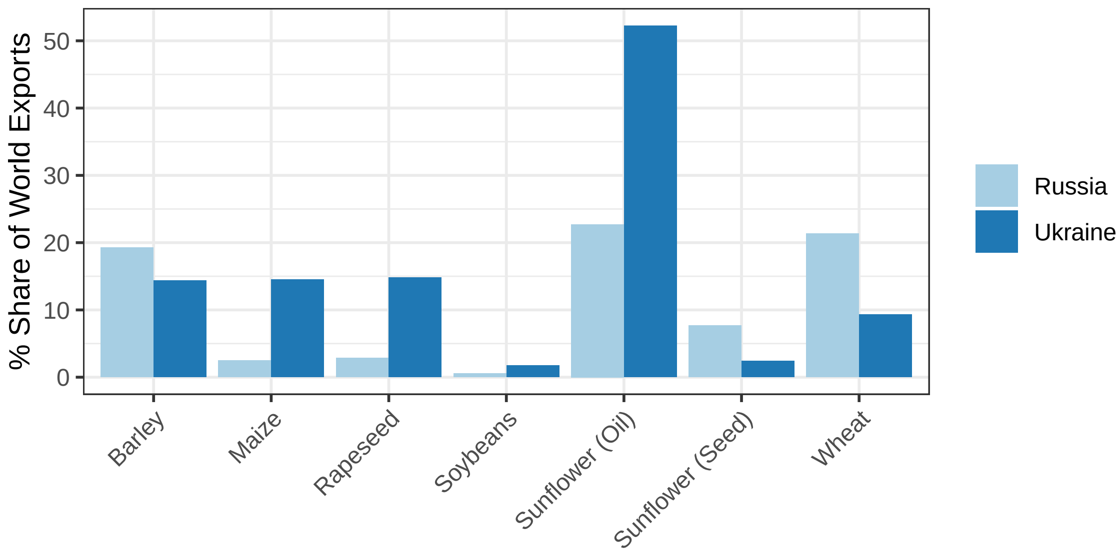

Figure S1. Sum of 2017-2021 exports over sum of world exports for selected commodities. Source: USDA (2022)

2 Crop and Food Prices

There have been various newspaper reports about the potential food security crisis related to the COVID-19 pandemic and the Russian invasion. See for example "War in Ukraine and Climate Change Could Combine to Create a Food Crisis" in the *Scientific American* on March 16, 2022 or "Ukraine War Threatens to Cause a Global Food Crisis" in the *New York Times* on March 20, 2022. The International Food Policy Research Institute (IFPRI) also published an issue post on April 13, 20022 related to export restrictions and the war in Ukraine titled "From bad to worse: How Russia-Ukraine war-related export restrictions exacerbate global food insecurity."

In this section, we highlight two additional aspects of commodity prices related to the war in Ukraine. First, the increase in food prices as measured by the FAO prior to the invasion and second, the price expectations of commodity markets.

2.1 FAO Food Price Index (FFPI)

The FFPI increased prior to the Russian invasion due to supply chain disruptions related to the COVID-19 pandemic (Figure S2). Data for the FAO Food Price Index (FFPI) can be downloaded here.

Figure S2. FAO Food Price Index in real terms from January 1990 to April 2022.

2.2 Future Prices

Settlement (closing) prices for May wheat futures were obtained from the Wall Street Journal for the years 2022, 2023, and 2024. The prices are reported in Table S1. The uncertainty associated with crop supply translated into a price surge for the May 2022 wheat futures, which increased by 35.8% between February 23 (the day prior to the invasion) and March 9. Futures prices for May 2023 and 2024 were not affected by March 9, which indicated that agricultural markets were not expecting the export disruption to go beyond the current year. The data for June 8 suggests that those expectations have changed since a substantial increase in the futures prices is observed.

				Δ compared to 23-Feb	
	23-Feb	9-Mar	8-Jun	9-Mar	8-Jun
May 2022 (WK22)	884.75	1201.50		35.8%	
May 2023 (WK23)	863.50	863.50	1118.5	0.0%	29.5%
May 2024 (WK24)	806.75	734.00	1040.0	-9.0%	28.9%

Table S1. May futures prices for wheat for 2022-2024. The last two columns represent the change (Δ) with respect price on the day prior to the invasion. Note that the underlying links will be invalid with the expiration of the contracts.

3 Scenario Development

The current situation and policy options had to be translated into scenarios which can be fed into an economic model. It is very difficult to make the effects of a war fit an agricultural trade model. For example, it is unclear if Ukrainian farmers are unable to export or unable to produce in the short- and/or medium-run. To capture this difference, we executed scenarios that are (1) setting exports exogenously to zero (i.e., all scenarios in the category *No Exports from Ukraine* in Tables S2 and S3) and (2) reducing production but leave the countries export ability (see *No Export Restrictions from Ukraine* in Tables S2 and S3). In addition, there have been news reports that Russia has banned exports into some other countries.[1]

Regarding policy proposals, there have been suggestions to bring back land into production that was under conservation programs.[2] Other propositions suggested to

[1]See Reuters (March 14, 2022) "Russia temporarily bans grain exports to ex-Soviet countries"

[2]See for example "EU allowing more land to be used for animal grazing labelled counter productive" in Euronews on March 21, 2022 or "Respond to Ukraine invasion with emergency crops on Conservation Reserve, says economist" in Successful Farming on March 3, 2022.

		Biofuel		
	RU Exp.	EU	US	UA Prod.
No Exports from Ukraine				
(A1) No UA Exports				
(A2) RU 50% Exports	50%			
(A3) EU-US 50% Bio		50%	50%	
No Export Restrictions from Ukraine				
(A4) UA Production 50%				50%

Table S2. Core scenarios summary in terms of reductions in exports from Ukraine, Russian export ability, biofuel reduction in the EU and U.S., and Ukraine production.

restrict maize use for biofuels to divert the freed up crop to food production.[3]

To capture the various aspects associated with the war, multiple scenarios were developed in line with the above mentioned issues. The scenarios are split into "core" (results presented in the main manuscript) and "side" (results presented in the Online Materials). All the scenarios are summarized in Tables S2 and S3. For the scenarios that restrict exports from Ukraine, the export values are exogenously set to zero in the model. Note that exports from Ukraine are zero for all scenarios except for (A4) and (B9).

4 Food Export Restrictions

The International Food Policy Research Institute (IFPRI) tracks the commodities by country that are subject to export bans, export taxes, or export licensing. The tracker is compiled by IFPRI researchers and can be accessed here. In the 21st week of 2022, a total of 20 countries have imposed actual export bans that are active and were verified by IFPRI. The IFPRI Food Export Restriction Tracker includes a measure of "Number of HS4 restricted products where the country has a global market share (Kcal) above 5 percent." Table S4 summarizes the countries and products for which that value is nonzero. HS4 refers to the 4-digit code of the Harmonized System. For example, 1003 is the HS4 code associated with barley.

[3] See for example "What the War in Ukraine Means for the World's Food Supply" in the New York Times on March 1, 2022 and "Cutting biofuels can help avoid global food shock from Ukraine war" in the New Scientist from March 14, 2022.

		Biofuel		
	RU Exp.	EU	US	UA Prod.
No Exports from Ukraine				
(B1) RU 25% Exports	25%			
(B2) RU 75% Exports	75%			
(B3) No RU-UA Exports	100%			
(B4) EU 50% Bio		50%		
(B5) US 50% Bio			50%	
(B6) RU 50% Exports and EU 50% Bio	50%		50%	
(B7) RU 50% Exports and US 50% Bio	50%	50%		
(B8) RU 50% Exports and EU-US 50% Bio	50%	50%	50%	
No Export Restrictions from Ukraine				
(B9) UA Production 25%				25%

Table S3. Side scenarios summary in terms of reductions in exports from Ukraine, Russian export ability, biofuel reduction in the EU and U.S., and Ukraine production.

Country	Products	HS4 #	Share
Egypt	Wheat, flour, oils, lentils, pasta, beans, gravel, mashedush	1	49.8%
Iran	Potatoes, eggplants, tomatoes, onion	2	6.1%
Kazakhstan	Wheat, wheat flour	1	68.7%
Russia	Sunflower seeds	1	0.3%
Russia	Wheat, meslin, rye, barley, maize, sugar	3	72.4%
Turkey	Cooking oils	1	15.4%
Ukraine	Wheat, oats, millet, sugar	2	28.4%

Table S4. Countries, products, and number of Harmonized System HS4 restricted products where the country has a global market share (Kcal) above 5%. Source: IFPRI Food Export Restriction Tracker

5 Scenario Results

The increase in commodity prices for the scenarios analyzed are reported in Table S5. Note that all results are reported in the Excel file `FoodClimate.xlsx` on the GitHub page (`www.github.com/foodclimate`) associated with this article.

6 Agricultural Trade and GHG Model

In this analysis, the CARD Long-Run Land-Use (CARD LRLU) Model is used to quantify the economic implications from the export restrictions in Russia and the Ukraine.[4] The most recent version of the model has been used to analyze the long-term impacts of climate change (Dumortier et al., 2021a). The modelling structure of the CARD LRLU Model is similar to a previous version of the model described in Carriquiry et al. (2020), Dumortier et al. (2021b), and Dumortier and Elobeid (2021). Although the CARD LRLU Model is able to project agricultural markets until 2050, the impacts over a 10-year period are used in this assessment. The greenhouse gas (GHG) model has been used previously as well and a detailed description can be be found in Carriquiry et al. (2020), Dumortier et al. (2021b), and Dumortier and Elobeid (2021). For this analysis, the GHG Model has been modified to cover the countries and regions in the CARD LRLU Model and includes carbon coefficients from West et al. (2010) besides the minimum, mean, and maximum coefficients. To compare the implications of Russian invasion, we run a baseline with no trade restrictions and compare the results to a scenario with zero exports for all commodities from Russia and Ukraine. In the following two sections, we briefly describe the modelling approach of both models.

6.1 CARD LRLU Model

The CARD LRLU Model is a partial equilibrium model which covers 22 major grain producing regions.[5] For each crop and region, demand is modelled for (per-capita) food, feed, and net exports. Demand is modeled as a function of own-price and cross-prices elasticities with respect to other crops, i.e., substitutes. The feed demand also depends on the size of the livestock industry which is assumed to be constant in this

[4] Center for Agricultural and Rural Development (CARD) at Iowa State University.

[5] Argentina, Australia, Brazil, Canada, Chile, China, Egypt, the European Union, India, Indonesia, Japan, Malaysia, Mexico, New Zealand, Nigeria, Peru, Russia, South Africa, Ukraine, the U.S., Vietnam, and the aggregate rest of the world (ROW) region. ROW close the model for trade equilibrium purposes.

	BA	MA	OP	RS	RI	SG	SB	SF	WH
(A1) No UA Exports	5.7%	3.9%	-0.5%	5.6%	0.3%	0.7%	3.3%	35.9%	3.6%
(A2) RU 50% Exports	9.9%	4.6%	-1.7%	7.2%	0.6%	0.7%	4.3%	62.4%	7.2%
(A3) EU-US 50% Bio	5.7%	-0.8%	-2.7%	-5.4%	0.2%	0.0%	3.7%	34.7%	3.5%
(A4) UA Production 50%	5.3%	2.8%	0.1%	4.1%	0.4%	0.7%	2.1%	21.8%	2.9%
(B1) RU 25% Exports	8.3%	4.3%	-1.1%	6.4%	0.4%	0.7%	4.1%	55.1%	5.5%
(B2) RU 75% Exports	11.5%	4.8%	-2.3%	7.9%	0.8%	0.8%	4.4%	69.8%	8.9%
(B3) No RU-UA Exports	13.1%	5.0%	-2.8%	8.7%	1.0%	0.9%	4.5%	77.0%	10.5%
(B4) EU 50% Bio	7.0%	4.6%	-2.7%	-5.4%	0.4%	1.1%	4.1%	34.8%	4.0%
(B5) US 50% Bio	4.3%	-1.5%	-0.5%	5.6%	0.1%	-0.3%	2.9%	35.8%	3.2%
(B6) RU 50% Exports and EU 50% Bio	11.2%	5.2%	-3.6%	-2.6%	0.7%	1.1%	5.0%	61.1%	7.5%
(B7) RU 50% Exports and US 50% Bio	8.2%	-1.1%	-1.1%	10.4%	0.4%	-0.4%	3.6%	62.8%	6.6%
(B8) RU 50% Exports and EU-US 50% Bio	9.9%	-0.2%	-3.6%	-2.6%	0.5%	0.0%	4.6%	61.0%	7.0%
(B9) UA Production 25%	2.7%	1.4%	0.1%	2.1%	0.2%	0.4%	1.1%	10.6%	1.5%

Table S5. Increase in crop prices compared to the baseline for all scenarios

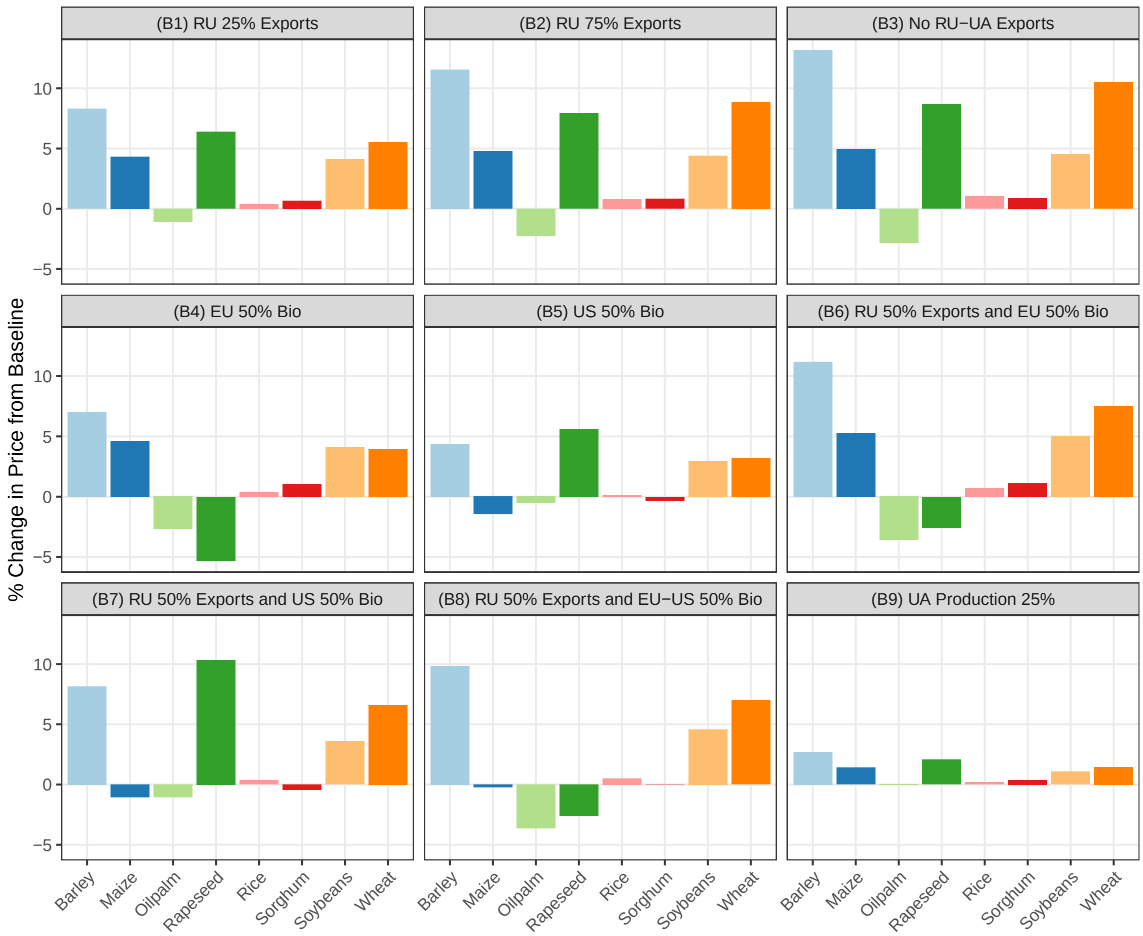

Figure S3. Change in price for the side cases.

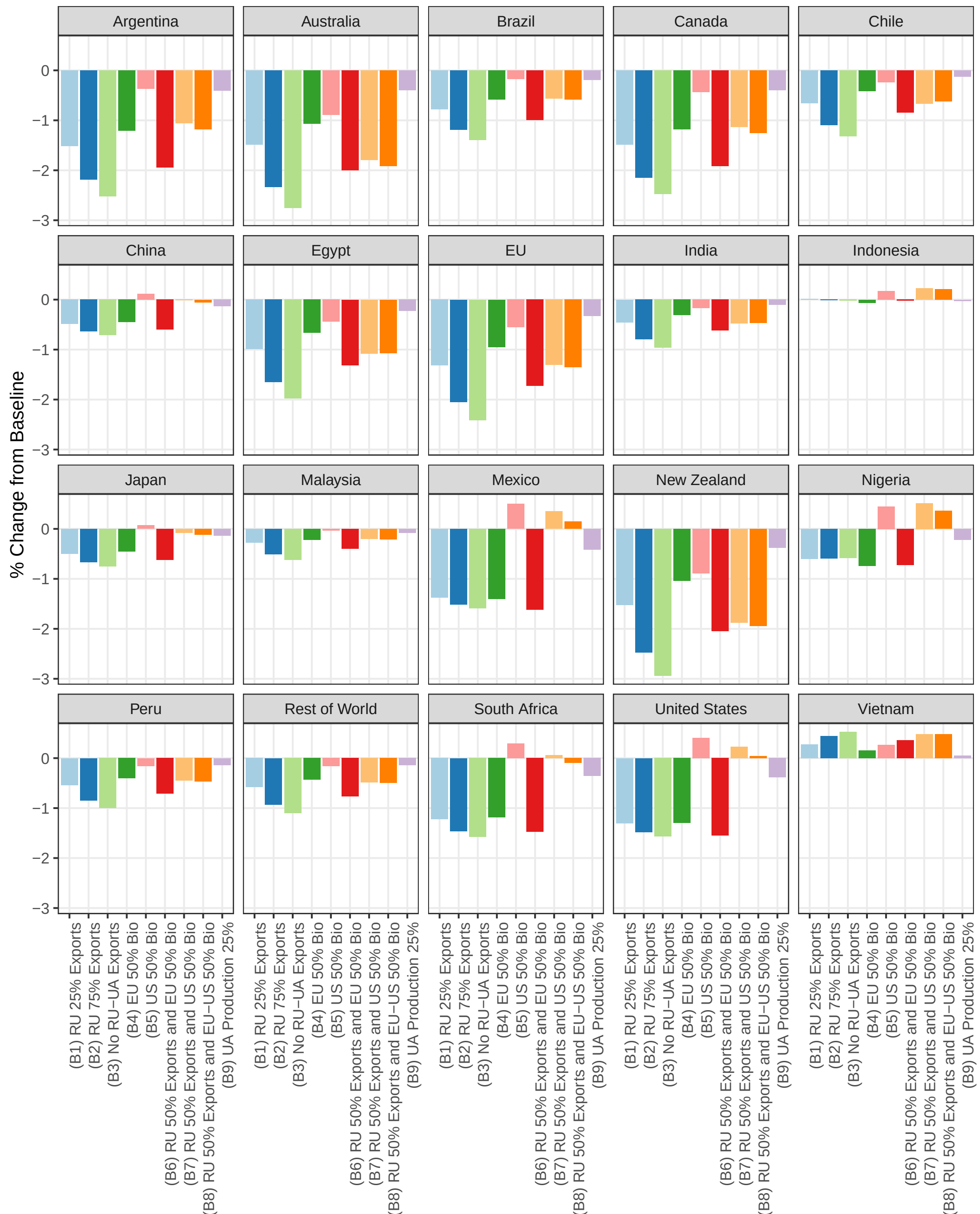

Figure S4. Change in per-capita food consumption for the side cases

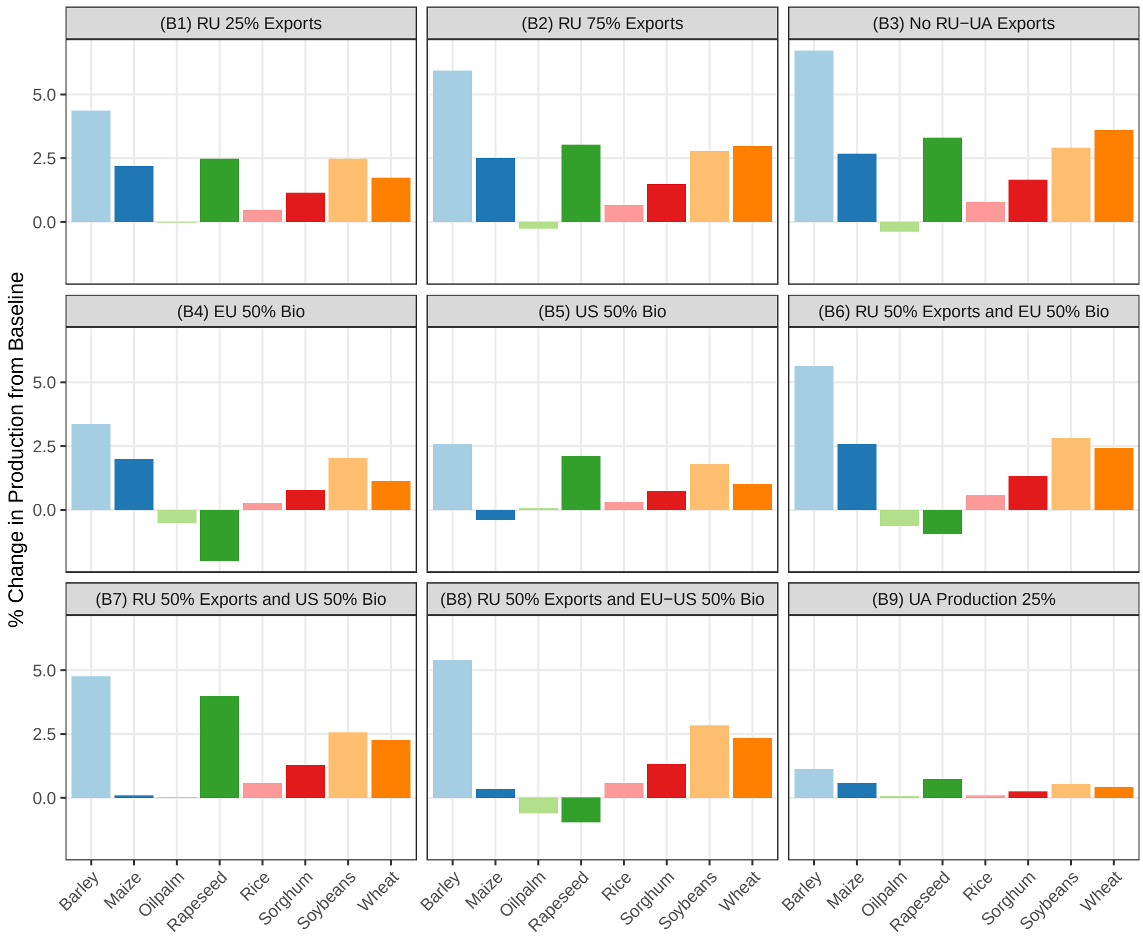

Figure S5. Change in production for the side cases analysis. In addition, gross domestic product (GDP) and GDP-squared determine the per-capita food demand. The squared term is included to avoid ever-expanding per-capita food consumption with income.

On the supply side, area allocated to a particular crop is based on the profitability of all crops to include competing uses of the land. Crop yields are projected based on data from the Food and Agriculture Organization (FAO) but also account for intensification by including yield-price elasticities. The CARD LRLU Model consists of a singular export market, i.e., bilateral trade relationships are not modeled but all exporting countries are supply a world market which needs to be cleared by the demand from the importing countries for each crop and year. The CARD LRLU Model determines a global time series of crop prices that equalizes supply and demand in the domestic as well as the net export markets.

6.2 GHG Model

The GHG Model is an ad-hoc model to the CARD LRLU Model and focuses on emissions from land-use change. In a first step, data from Gibbs (2006) on global land cover and global ecological zones are combined to obtain land cover based on the classification of Olson et al. (1985). Second, carbon coefficients are assigned to each grid cell based on land cover and ecological zones. Those carbon coefficients are obtained from Gibbs (2006) who reports minimum, mean, and maximum values due to the uncertainty in estimating biomass carbon. The GHG model also includes data from West et al. (2010) of carbon in potential vegetation. The figures in the main manuscript indicate that the carbon coefficients in potential vegetation of West et al. (2010) correspond closely to the maximum estimates by Gibbs (2006).

The crop distribution for the crops modelled is obtained from Monfreda et al. (2008). A region's change in crop area translate proportionally to changes in each grid cell. That is, a grid cell containing 1% of a region's production will contain the same proportion after the area change. Second, within a grid cell, there is perfect substitutability of different crops. Hence, the area of all four crops within a grid cell is summed up and the increase in one crop can be compensated by the decrease of another crop. Based on the carbon coefficients associated with the land cover in a particular cell, carbon emissions can be calculated.

7 Population in the CARD LRLU Regions

Table S6 shows the 2020 population numbers in the CARD LRLU regions. This table can help interpret the population affected under the various scenarios.

Country	Population	Share
ARG	45.38	0.59%
AUS	25.69	0.33%
BRA	212.56	2.75%
CAN	38.04	0.49%
CHL	19.12	0.25%
CHN	1410.93	18.24%
EGY	102.33	1.32%
EU	514.69	6.65%
IDN	273.52	3.54%
IND	1380.00	17.84%
JPN	125.84	1.63%
MEX	128.93	1.67%
MYS	32.37	0.42%
NGA	206.14	2.66%
NZL	5.08	0.07%
PER	32.97	0.43%
ROW	2506.38	32.40%
RUS	144.10	1.86%
UKR	44.13	0.57%
USA	331.50	4.28%
VNM	97.34	1.26%
ZAF	59.31	0.77%

Table S6. Population in the 22 CARD LRLU regions in 2020. Source: World Bank WDI SP.POP.TOTL.

8 Food Insecurity

The CARD LRLU Region "Rest of the World" (ROW) contains a large number of countries including some of the world's poorest. The decline in per-capita food consumption resulting from our scenarios needs some differentiated interpretation. To do so, we have downloaded two data series from FAOSTAT: (1) Share of dietary energy supply derived from cereals, roots and tubers (kcal/cap/day) (3-year average) and (2) Number of moderately or severely food insecure people (million) (3-year average). The 3-year average data is for 2017-2019.

The per-capita food consumption in our analysis includes only the grains modelled and does not include many other food items. In ROW in general and in the poorest countries in particular, grains represent a much higher share from total caloric intake than in more affluent countries. For example, Figure S6 illustrates the spread of countries for ROW and the EU. Some of the lowest shares of cereal, roots, and tubers are observed for the U.S. (23%), Australia (24%), and Brazil (31%) among others. Hence, a price increase for grains has a stronger impact in countries with a high share of grains consumption.

Figure S7 shows the population share of moderately or severely food insecure people in the countries modelled (China has not data available). Again, the Rest of the World has a significant number of food insecure people. A decline in per-capita food consumption in countries with an already lower baseline caloric intake has significant welfare effects.

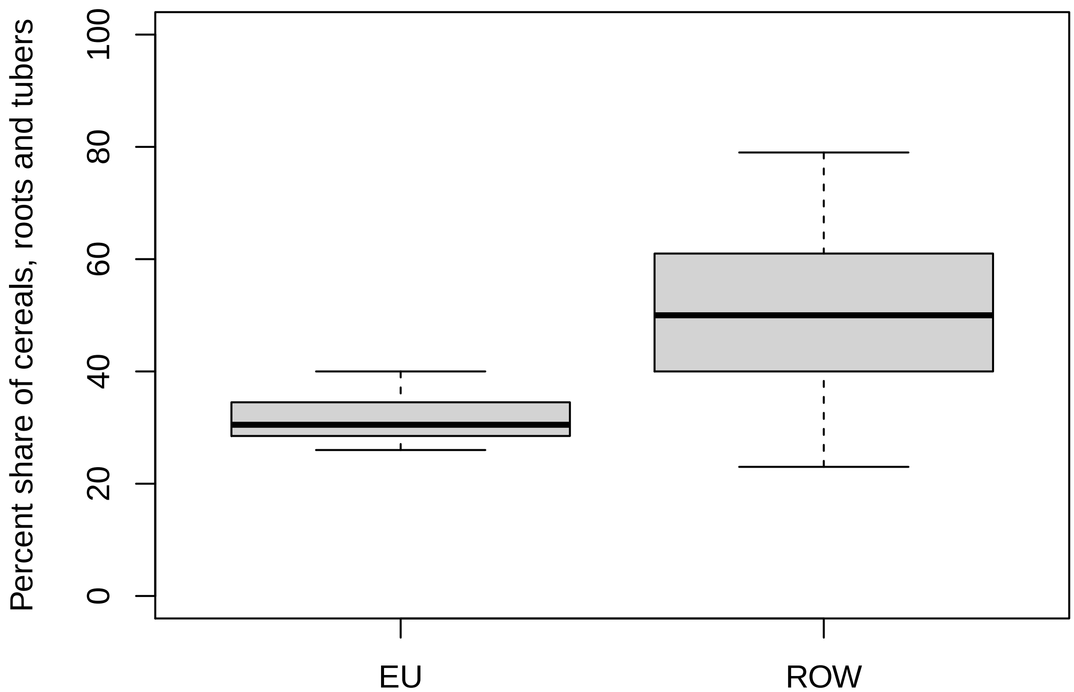

Figure S6. Share of dietary energy supply derived from cereals, roots and tubers (kcal/cap/day) (3-year average)

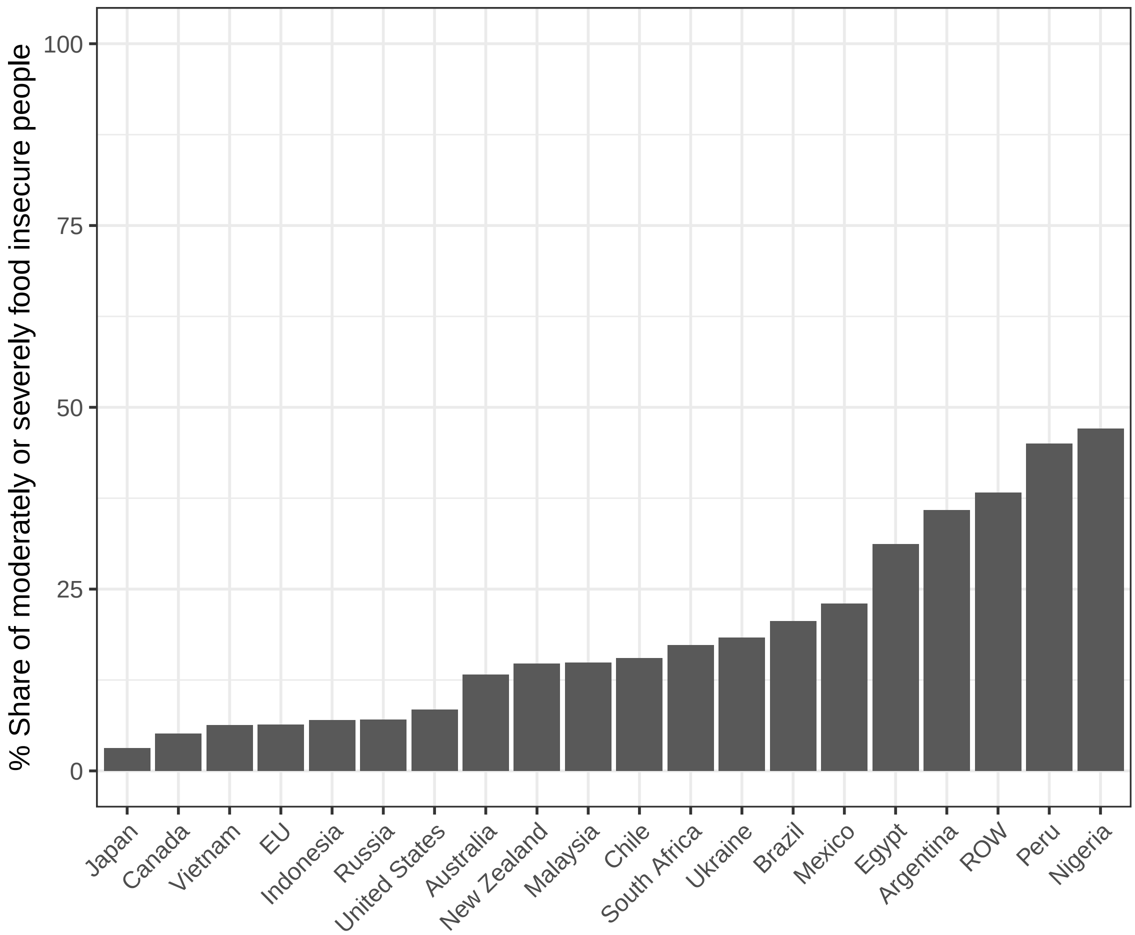

Figure S7. Number of moderately or severely food insecure people (million) (2017-2019)

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