The impact of the Ukraine conflict on world grains prices

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Abstract

The war in Ukraine, which started in February 2022, has disrupted the important Black Sea grain trade. At the same time, and partly as a consequence of the war and of Western sanctions, both energy and fertilizer prices have soared. Many commentators have attributed rises in food prices on world markets to the Ukraine conflict. The paper reports an analysis of the impact of the war on wheat and corn prices in the world market. The estimates are obtained from an empirical implementation of the competitive storage model. The model links the prices of hard wheat and corn to grain availability, grain stocks and crude oil and fertilizer prices taking into account the Black Sea Grains Initiative (BSGI). Three counterfactuals are analyzed – "no war", "no BSGI" and "no sanctions".

Keyword: wheats, corn, Ukraine, war, fertilizers

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1. Introduction

The conflict in Ukraine has had a major impact on the export of grains through Black Sea ports and also has potentially limited Ukrainian grain production. Wheat prices rose by one third in the initial three months of the conflict. Many commentators have attributed rises in food prices on world markets to the Ukraine conflict.[1] This paper analyzes the extent to which these increased prices are indeed attributable to the conflict.

Ukraine produces and exports both wheat (hard red winter) and corn (maize). Figure 1 plots deflated wheat and corn prices over the two most recent decades.[2] The chart is dominated by the sharp rise in prices in the 2007/08 crop year, and, following a gap in 2008/09 and 2009/10, continuing high prices through to 2013/14. Prices then dropped back to their levels at the start of the millennium. The low point occurred in 2019/20 with the onset of Covid. The subsequent recovery lead to a rise of around 25% in the price of hard wheat and of 40% in the price of corn. The conflict in Ukraine broke out in February 2022, four and a half months into the 2021/22 crop year. The corn price continued to rise but by a more modest 10% while the hard wheat price surged by a further 30% to reach those approaching those experienced in 2007-8, 2010/11 and 2012-13. At the time of writing (February 2023), grains prices have fallen back from their 2022 peaks, fairly modestly in the case of wheat but more dramatically for corn.

Ukraine is an important producer and exporter of both wheat and corn. Averaging over the three crop years 2017/18, 2018/19 and 2019/20, Ukraine accounted for 10% of world wheat exports and 15% of corn exports. The Russian Federation is also an important wheat exporter accounting for 20% of world wheat exports over the same period.[3] Figure 2 shows Ukrainian and Russian wheat and corn since 2017/18.[4] Ukraine enjoyed a very good harvest in 2021/22, as did Russia. Given these percentages, disruption in the Black Sea region evidently has the potential to have a major impact on grains prices.

I identify five channels through which the Ukraine conflict may have had an impact on grains prices. The first two of these channels operate directly through Ukrainian grain commerce leading to what I refer to as the "direct" impacts of the conflict.

a) It was reasonable to expect that, consequent on the conflict, Ukraine would harvest less grain in 2021/22 than had previously been expected; and that it will be

[1] For example, "Russia's invasion of Ukraine is raising food prices across the world. … The war in Ukraine, as well as sanctions against Russia, have resulted in a massive decline in the supply of major staple foods. This has led to a rise in food prices globally". Economics Observatory, 21 June 2022. https://www.economicsobservatory.com/how-is-the-war-in-ukraine-affecting-global-food-prices

[2] Source: World Bank, "Pink sheets". The 2022-23 figures are for October-January.

[3] Source: USDA, WASDE. "World" excludes China throughout this paper. Russia is not an important corn exporter.

[4] Source: USDA, WASDE. The 2021/22 numbers are estimates.

able to plant less for the 2022/23 crop. This will have resulted in grain availability in both crop years.

b) Disruption of the Black Sea grains trade may result in Ukrainian grain being unavailable for export. This could either result in involuntary stockholding, breaking the established relationship between stocks and prices, or additional domestic grain consumption.

In addition, three are "indirect" impacts which arise out of Western sanctions and other trade limitations which may have raised the prices of fertilizers and other inputs worldwide. Specifically

c) Western sanctions on the supply of fertilizers from Belarus and Russia may have raised grain production costs and depressed harvests throughout the world.
d) Western sanctions on the exports of Russian crude oil and also petroleum derivatives may have raised oil prices impacting both fertilizer prices and grain production costs.
e) Natural gas is an important feedstock for urea. The decision by European countries to limit imports of Russian natural gas has made most urea production in Europe uneconomic raising fertilizer prices.

The analysis relies on a comparison of actual grains prices with those that would have occurred in the absence of the Ukraine conflict. In other words, it reports a counterfactual or "what if" analysis. Section 2 of the paper discusses the specification of the counterfactuals employed in the subsequent sections. Section 3 reviews the supply-demand balance in the wheat and corn markets in the 2020/21 crop year prior to the Ukraine conflict. In section 4, I discuss the impact of the Ukraine conflict on Ukrainian production and exports of wheat and corn. Section 5 considers the effects of the Black Sea Grain Initiative (BSGI), negotiated in July 2022 under the auspices of the United Nations. The estimated impact of the conflict on Ukrainian production and exports (with and without the BSGI) allow evaluation of the direct price impact of the conflict. Results are reported in section 6. These estimates ignore impacts of western sanctions and other actions on energy and fertilizer prices. I analyze these indirect impacts in section 7. Section 8 concludes.

2. Counterfactual methodology and model structure

The analysis is constructed round three counterfactuals:

a) The Ukraine conflict did not take place. In this counterfactual Ukraine would have been able to produce and export without impediment. (The analysis assumes that the conflict had no impact on the ability of other countries to produce and export grains).
b) Absence of the BSGI. The BSGI was negotiated to facilitate Ukraine's Black Sea grain exports notwithstanding the conflict. To the extent that the initiative has been

successful, the BSGI has offset the problems that Ukraine has experienced in exporting (but not in producing).

c) Absence of western sanctions and other restrictions on Russian and Belarus energy and fertilizer exports plus absence of European actions to reduce dependence on Russian natural gas. This counterfactual supposes no war-induced rise in crude oil and natural gas prices and consequently no war-induced rise in fertilizer prices.

Comparison of the observed time paths of the actual levels of Ukrainian grains production and exports with those that would have been expected in the scenarios defined by counterfactual (a) and (b) allows estimation of the *direct* physical impacts of the conflict.

The "no war" counterfactual is implemented using an argument analogous to those underlying event studies. Event studies are widely used in financial economics to study the effects of surprise announcements such as takeovers or earnings warnings (MacKinlay, 1997). Provided the event "window" is short, it can be assumed that any change in the share or other price under consideration can be attributed to the event and not to external factors. In the current instance, the event is the Russian invasion of Ukraine on 24 February 2022 and the window is a two week period on either side of the start of the conflict. The event was a surprise although there was some discussion of this possibility in the weeks prior to 24 February.[5]

The USDA publishes its World Agricultural Supply and Demand Estimates (WASDE) reports in the second week of each month. These reports list the USDA's expectation of grain production and consumption levels in the current (northern hemisphere) crop year and an estimate of end crop-year stocks. These estimates relate to the United States itself but also to the world and to leading grain exporters and importers. I define the conflict event window as the one month period between the February and March WASDE reports (9 February 2022 and 9 March 2022). I have not found any non-conflict related news events relating to the Ukrainian grains sector appearing within this widow.[6] Confrontation of the March 2022 WASDE estimates of Ukraine's likely 2021/22 production, consumption and exports for wheat and corn with those made in the February report generate a direct measure of the direct physical effects of the Ukraine conflict, as perceived by USDA analysts. (While it is possible that other market analysts may have taken different views, WASDE reports are authoritative and often form the starting point for external analyses).[7]

[5] A number of press reports on 22 and 23 February suggested that an invasion was imminent. On 12 February 2022, the BBC reported a US State Department warning that Russia could invade "at any time". https://www.bbc.com/news/world-europe-60355295

[6] A *Farm Policy News* discussion dated 15 February 2022 surveyed recent reports on Ukrainian wheat and corn commerce. The report noted some changes in the destinations of Ukrainian exports. See Good (2022).

[7] The Ukrainian Grains Association reproduced the WASDE reports on its own website: https://uga.ua/en/balances/

Definition of a counterfactual for the 2022/23 crop year is more complicated since the USDA published its initial forecasts for the 2022/23 crop year in the May 2022 WASDE report. This report appeared two months after the start of the conflict. Absent a pre-conflict USDA projection, I construct the counterfactual by comparing the May 2022 WASDE projections with average Ukrainian production and consumption levels in the immediately preceding years.

The ”no BSGI” counterfactual (b) is more straightforward. The BSGI was negotiated in July 2022 once it became clear that conflict was likely to continue over an extended period. The March and May 2022 WASDE reports predate these negotiations. Shipments under the BSGI are well documented.[8] The counterfactual is defined by supposing that the shipments made through the BSGI did not take place and that these quantities of grain either remained blocked in Ukrainian ports or were diverted into domestic consumption. At the time of writing, negotiations are still taking place to extend the BSGI beyond March 2023 when the initial agreement is due to lapse.

The price impacts of these physical impacts are inferred from a simple empirical implementations of the competitive storage model (Williams and Wright, 1991). This model sees grains prices as determined by the willingness of stockholders to finance the carryover from one crop year to the next. Prices within the crop year therefore reflect expectations of the end crop year stock and hence the likely carryover to the following crop year. Any reduction in Ukrainian production levels will have reduced the expected carryover and hence raised prices. Restrictions on exports will have blocked inventory within Ukraine. Involuntary stockholding, expected to persist into the next crop year or beyond, reduces availability on the world market and raises prices in the same way as a reduction in production.

The grains price model takes energy and fertilizer prices as given. These prices will have been affected by western responses to the Russian invasion of Ukraine and not by events in Ukraine itself. I regard these as *indirect* effects of the conflict. Western governments have taken a number of actions against Russia and ally Belarus. These include sanctions both on imports and persons. The most important in the current context are the decisions to limit, and in many cases eliminate, imports of crude oil from Russia and the European decision to substantially reduce imports of natural gas. The “no sanctions” counterfactual (c) supposes that these restrictions did not take place. The crude oil price is seen as having a small direct impact on grains prices but the main impact of the change in energy prices come through the pass-through into fertilizer prices. The resulting price rises have raised agricultural production costs throughout the world.

The “no sanctions” counterfactual is implemented within a five variable Cointegrated Vector AutoRegression (CVAR) linking the changes in crude oil, natural gas, Diammonium Phosphate (DAP) and urea prices, and an economic activity variable. The urea prices

[8] https://www.un.org/en/black-sea-grain-initiative/vessel-movements

depends on the (Amsterdam) natural gas price and both the DAP and urea prices depend on the crude oil price. The counterfactual is defined by simulation of the CVAR forward from the start of the conflict. These counterfactual crude oil and fertilizer prices are then fed back into the grains model to provide an estimate of the indirect impact of the conflict on grains prices.

3. COVID-19 and the 2020/21 crop year

Grains prices had been relatively stable at a low level over the five crop years 2014/15 to 2019/20 – see Figure 1. The COVID-19 virus infection (henceforth Covid) emerged in Wuhan, China, in December 2019 and had spread outside China's borders by February 2020. Italy was the first country to introduce a nationwide lockdown in early March 2020 and it has been estimated that by the end of April 2020 half the world's population was subject to lockdown restrictions.[9] The pandemic and the restrictions had a strongly negative but uneven impact on economic activity. The World Bank asserted that the pandemic caused "the largest global crisis in more than a century" (World Bank, 2022). The impact varied over countries depending on the severity of the restrictions on movement and on industries within each country (Klein and Smith, 2021). This economic impact was more severe in Europe than the United States.

Europe started to recover from the Covid shock over the summer of 2020 as infections waned in the warmer weather and then with the prospect of vaccination (Milesi-Ferretti, 2021). China's "zero Covid" policy generated a very different time path. The Chinese government was successful in insulating the wider economy from the initial outbreak in Wuhan but the costs of the policy rapidly increased through 2022 under the influence of the highly infectious omicron variant of the virus. These costs resulted in a marked slowdown of activity in the second half of 2022 leading to abandonment of the policy at the end of the year.[10]

Agriculture itself suffered relatively little (Bhattacharya, 2021). The demand for food held up, because of low income elasticities but also as home consumption replaced eating out. By contrast, the demand for industrial raw materials was hit hard by the contraction and travel restrictions led to large declines in the transportation and tourism sectors. The average price of Brent crude fell from $64.03 in 2019 to $42.30 in 2020, a fall of 33.9%. This price recovered to average $70.44 in 2021. The Covid rebound also generated a doubling in (nominal) fertilizer prices, which had been little changed through 2020 – the urea price rose from $312/ton to $601/ton while DAP rose from $219/ton to $483/ton. These rises matched rises in metals prices – the price of aluminum on the London Metal Exchange (LME) rose

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[9] https://www.euronews.com/2020/04/02/coronavirus-in-europe-spain-s-death-toll-hits-10-000-after-record-950-new-deaths-in-24-hou

[10] Liang, A., and P. Hoskins. "Covid: China 2022 economic growth hit by coronavirus restrictions". BBC. https://www.bbc.com/news/business-64286126

from $1704/ton in 2020 to $2480/ton in 2021, a rise of 45.5%, and that of copper from $6182/ton to $9317/ton, a rise of 51.8%.[11]

Fertilizer prices are rapidly transmitted into grains prices (Vatsa, Miljkovic and Baek, 2023). The US export price of hard wheat rose by 30% over the 2020/21 crop year ($272/ton in October 2020 to $355/ton in October 2021) and that of corn by 28% ($187/ton to $240/ton). The wheat market was relatively tranquil in terms of supply and demand shocks over 2020/21. This may be seen from Table 1. The world wheat harvest exceeded the USDA's pre-harvest projection by just 1.1% while total consumption exceeded the initial estimate by 1.4%. The situation is slightly more complicated in corn where the world harvest was 6.3% lower than the USDA's initial projection[12] but world consumption was also lower (by 3.1%). Crude oil and fertilizer prices therefore appear stronger candidates for explaining grains price rises in the 2020/21 crop year than do physical imbalances in the grains markets.

Table 1
Projections and estimates of the world wheat and corn 2020/21 balances

		Initial projection May 2020	Post-harvest estimate November 2020	Most recent estimate March 2023
Wheat	Production	633.5	636.4	640.2
	Total consumption	623.5	621.7	632.7
	Net Chinese imports	5.0	7.0	9.9
Corn	Production	926.9	884.6	868.7
	Total consumption	887.0	874.5	859.0
	Net Chinese imports	7.0	7.0	29.5

The table reports the extra-Chinese world supply-demand balance for the 2020/21 crop year taken from the May 2020, November 2020 and March 2023 WASDE reports.
All quantities are in million metric tons (mmt).

Grains prices continued to rise in the initial, pre-conflict, months of the 2021/22 crop year. The wheat price rose by a further 5.5% to average $374/ton in January 2022 while the corn price rose 15.4% to $277/ton. Prices in the first four months of the new crop year were higher, in deflated terms, than those since 2013 and 2014, at the end of the previous period of high grains prices.

In summary, the Ukraine conflict emerged at a time when grains prices were already high and still continuing to rise. The high prices prevailing at the end of (calendar year) 2021, prior to the start of the conflict, cannot be linked to the Ukraine conflict.

[11] Prices quoted in this section are all undeflated.
[12] The largest shortfall was in Brazil.

4. The Ukrainian grains balance in the 2021/22 and 2022/23 crop years

I first consider the impact of the conflict on Ukrainian production, consumption and stockholding of grains. Reductions in domestic production reduces world grains availability. Logistical and other problems that divert grain into domestic consumption will have the same effect. Moreover, logistical problems may also give rise to involuntary stockholding as grain supplies are blocked either in farms or at the ports. Involuntary stockholding therefore acts like additional consumption.

The market clearing identity within each country is

$$\text{Stock change} = \text{Production} - \text{Consumption} - \text{Net exports} \quad (1)$$

Ukraine has historically held very low carryovers so it is reasonable to the whole of any stock increase as involuntary. On these assumptions, identity (1) can be re-expressed as

$$\Delta\text{Production} - \Delta\text{Consumption} - \text{Unintended stock change} = \Delta\text{Net exports} \quad (2)$$

where Δ indicates the difference between the observed values and those implied by a no conflict counterfactual. This allows me to focus on the reduction of (net) exports from Ukraine as measuring the direct impact of the conflict.[13]

I start by quantifying harvest shortfalls implied by the USDA's WASDE reports. The February 2022 WASDE report, containing projections for the 2021/22 crop year, was published on 9 February 2022, 15 days prior to the start of the conflict. Although there was some concern about the situation in Ukraine, the markets were more preoccupied by developments in the Argentinian wheat and Brazilian corn markets.[14] I take the numbers in the February report as representing the best estimates of the USDA statisticians for Ukrainian wheat and corn production and exports in 2021/22 prior to the outbreak of hostilities. These projections define the "no conflict" counterfactual for crop year 2021/22.

I obtain a preliminary estimate of the impact of the conflict by comparing the February projections with the revised projections in the March WASDE report (release date 9 March 2022).The March report did not alter the Ukrainian wheat and corn production forecasts but did include a downward revision to expected exports. Market commentators now appear to have become more focused on projected rises in Australian and Indian wheat exports.[15] Comparison of the estimates in the February and March reports gives a before-after

[13] Ukrainian imports of wheat and corn are negligibly small and can effectively be neglected. It is possible to perform the same analysis for exports from the Russian Federation. However, the WASDE figures show no evidence of any reduction in projected Russian wheat exports over the event window.

[14] https://www.dtnpf.com/agriculture/web/ag/news/article/2022/02/09/february-2022-wasde-report-holds

[15] https://www.dtnpf.com/agriculture/web/ag/news/business-inputs/article/2022/03/10/march-wasde-report-huge-surprise

assessment of the expected impact of the conflict on production, exports and stocks changes.

The initial Russian conflict objective involved an armored convoy proceeding from the Belarus border towards Kyiv with the objective of forcing a change in government. It was only in the second week of March that it became clear that the Russians would be unable to capture Kyiv and that the war would be likely to be considerably longer than many, including the Russian government, had supposed. I therefore use a second set of estimates derived by comparing the February WASDE estimates with the May estimate (released 12 May 2022). This is after the end of the 2021/22 crop year but data are still provisional. Comparison of the most recent estimates (at the time of writing, from the March 2023 WASDE report) with those in the February 2022 report give a revised estimate of the conflict impact, subject to the qualification that other factors, unrelated to the conflict, may have affected the sectors in the intervening eight conflict months.

Table 2
Estimated Ukrainian grains balance, 2021/22 crop year (mmt)

		Wheat	Corn
Feb. 2022 closing stock projection		2.0	1.5
Production shortfall	March 2022	0.0	0.1
	May 2022	0.0	-0.1
	March 2023	0.0	-0.1
Export (net) shortfall	March 2022	4.0	6.0
	May 2022	5.0	10.5
	March 2023	5.2 (6.7)	6.5 (9.0)
Increased consumption	March 2022	1.0	3.0
	May 2022	1.4	5.3
	March 2023	1.4	3.0
End stock projection	March 2022	5.0	4.4
	May 2022	5.6	6.8
	March 2023	5.8 (7.3)	5.1 (7.6)
Induced stock change	March 2022	3.0	2.9
	May 2022	3.6	5.3
	March 2023	3.8 (5.3)	3.6 (6.1)

Shortfalls are measured as the difference between the quantities projected in the February 2022 WASDE report with the revised projections in the March and May 2022 reports and the estimates in the March 2023 report. Figures in parentheses estimate counterfactual export and stock projections in the absence of the BSGI and on the assumption that production and consumption remain unvaried.
All quantities are in million metric tons (mmt).

Table 2 summarizes the comparisons for the 2021/22 crop year. Rows 2-4 of the table show that the USDA projections of the Ukrainian 2021/22 wheat harvest remained unchanged from the pre-conflict levels. Figures 4 and 5 show the regional distribution of wheat and corn production respectively in Ukraine. Wheat production is concentrated in the south of the country with between 20% and 28% of the total taking place in areas currently under Russian occupation. Winter wheat, planted in October and November, is the dominant wheat crop in Ukraine,[16] explaining why the 2021/22 crop was unaffected by the war. Corn is a summer crop[17] and is grown further north in areas which have remained almost entirely under government control.

The main war effects in 2021/22 were therefore on exports, both of wheat and corn – rows 5-7 of Table 2. The USDA increased its assessment of the wheat export shortfall from 4.0 mmt in March to 5.0 mmt in May as the likely duration of the conflict increased. The corn export shortfall was seen as rising from 6.0 mmt to 10.5 mmt in response to heavy fighting in the north of the country. This estimate was subsequently revised down once the Russian attack on Kyiv was repelled and fighting switched to the south. Ukrainian grain exports have benefited from some diversion from the Black Sea to land routes to Poland and Romania but this has affected corn more than wheat.[18]

Increased grains consumption is one response to difficulties in exporting. Rows 8-10 of Table 2 shows a projected 2021/22 increase in wheat consumption of 1.4 mmt and corn consumption of 3.0 mmt (projected at 5.3 mmt in May) in Ukraine. The disaggregated WASDE numbers show that this increase is entirely in consumption in the form of animal feed, possibly substituting imported feeds. Closing stock estimates (Table 1, rows 11-13) are simply the sum of opening stocks plus production less net exports and consumption. Any production shortfall reduces the closing stock estimate while export shortfalls increase the estimate.

The most recent WASDE estimates will have been made taking the BSGI export information into account. Table 2 also lists, in parentheses, the export shortfalls that would have resulted in the absence of the BSGI shipments on the assumption that these quantities would have been added to stock and that production and consumption remained unchanged. The estimates show that, absent the BSGI, the projected 2021/22 wheat export shortfall would have increased through the summer of 2022 while the corn shortfall would have remained close to the high level projected in May. I discuss the BSGI in section 5, below.

Inferences for the 2022/23 conflict are more complicated for two reasons. The USDA releases its first crop estimates for the new crop year in May so no pre-conflict WASDE estimate is available for the new crop year. In the calculations reported below, I suppose that, absent both weather problems and the conflict, wheat and corn production levels would be at their average over the four crop years 2018/19 to 2021/22. Second,

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[16] https://ipad.fas.usda.gov/highlights/2020/01/ukraine/index.pdf

[17] https://beef2live.com/story-ukraine-agricultural-overview-85-142901

[18] Eurostat reports imports of 0.2 mmt and 0.3 mmt of wheat into Poland and Romania respectively from Ukraine in the seven months March-October 2022. The corresponding figures for corn are 1.4 mmt and 0.5 mmt. Imports were negligible in the corresponding months of 2020 and 2021.

approximately one quarter of the Ukrainian wheat-producing area is currently under Russian occupation.

Wheat produced in these occupied oblasts will be reported to the Russian statistical agencies and hence attributed to Russia in the trade statistics. It is therefore important to distinguish the shortfall in exports to the sovereign country Ukraine and the shortfall of exports from the geographical area defined by Ukraine's internationally recognized boundaries. Wheat produced in and exported from the occupied oblasts is a loss to Ukraine but not to the world wheat economy. I assume that 20% of Ukrainian wheat production takes place in the occupied oblasts and re-attribute these quantities to Ukraine.[19] I regard shortfalls in production and exports and increases in consumption as taking place entirely in the controlled oblasts. (This problem is absent for corn since almost all production remains in the controlled oblasts).

Table 3
Expected Ukrainian grains balances (mmt), 2022/23

		Wheat			Corn
		Controlled	Occupied	Total	
Average 2018/19 – 2021/22	Harvest	-	-	28.1	34.9
	Net exports	-	-	18.8	28.6
	Consumption	-	-	9.3	6.1
WASDE May 2022	Harvest	21.0	*5.6*	26.6	19.5
	Expected shortfall	-	-	1.5	15.4
	Net exports	13.0	*3.8*	16.8	9.0
	Expected shortfall	-	-	2.0	19.6
	Consumption	9.2	*1.9*	11.1	9.2
	Excess over normal	-	-	1.8	3.2
	Stock change	-1.1	-	-	1.3
WASDE March 2023	Harvest	21.0	*5.6*	26.6	27.0
	Expected shortfall	-	-	1.5	7.9
	Net exports	13.5 (1.9)	*3.8*	17.3 (5.7)	23.5 (3.4)
	Expected shortfall	-	-	1.6 (13.1)	5.1 (25.2)
	Consumption	9.2	*1.9*	11.1	6.2
	Excess over normal	-	-	1.8	0.2
	Stock change	-1.6 (11.3)	-	-	-2.7 (21.2)

Figures for the occupied Ukrainian blasts (italicized) are calculated by assuming that the occupied oblasts produce, export and consume 24% of the historical Ukrainian average for the respective aggregates and that this is unaffected by the conflict. The expected harvest and export shortfalls are calculated relative to the historical averages (2018/19 – 2021/22). Italicized numbers refer to production, consumption and exports in occupied oblasts and reallocated from the corresponding figures for the Russian Federation. Figures in parentheses estimate counterfactual projections in the absence of the BSGI and on the assumption that production and consumption remain unvaried.
Source: Author's calculations based on USDA, WASDE reports, May 2022 and March 2023.

[19] I am grateful to Andrey Sizov for advice on this proportion.

The Ukrainian wheat balance estimates deriving from the May 2022 WASDE report and reported in the second block of Table 3, show projected Ukrainian wheat production precisely in line with historical levels. As with the 2021/22 crop, the estimates only show a small export shortfall of 1.3 mmt in Ukraine. Domestic wheat consumption is seen as higher than expected on the basis of historical figures. The final block of Table 3 gives the updated estimates for 2022-23 derived from the March 2023 WASDE report. There is no change to the projected production level but projected exports are higher almost totally eliminating the estimated export shortfall.

The final column of Table 3 gives the corresponding estimates for corn. These show a sharp reduction in both Ukrainian production and exports. The principal cause of the production shortfall appears to be the exceptionally heavy rain which has muddied the land making it difficult to work. [20] The presence of unexploded munitions is a supplementary factor. Ukrainian government sources are even more pessimistic with the Minister for Agriculture indicating a fall to between 22 mmt and 23 mmt citing a lack of fuel and funds for the harvest.[21] A government minister is reported as stating that harvesting might still be possible in the spring, but at the expense of a deterioration in quality. For consistency, I remain with the WASDE projections. Three factors therefore appear responsible the projected 2022/23 Ukrainian corn shortfalls – reduced production due to excess rain, reduced production as the consequence of conflict-related problems, and supra-normal consumption.

Tables 2 and 3 list the export shortfalls but an element of judgement is required in deciding the extent to which these shortfalls were due to conflict as distinct from other factors, in particular weather. I have made the following assumptions in interpreting these tables:

- The March 2022 WASDE report, issued in the weeks immediately following the Russian invasion, already predicted export shortfalls for 2021/22 both for wheat and corn. There is no record of important weather developments in February 2022. I attribute these projected shortfalls entirely to the conflict.
- In the absence of weather reports suggesting otherwise, I regard the relatively small projected Ukrainian 2022/23 wheat export shortfalls as entirely due to the conflict.
- The WASDE projections for the 2022/23 crop year take into account adverse weather impacts on corn production. It is not easy to disentangle these factors. In the

[20] https://www.foodingredientsfirst.com/news/ukraine-corn-production-declines-while-corn-wheat-and-sunflower-seed-forecasts-look-weak.html

[21] https://www.agweb.com/markets/pro-farmer-analysis/ukrainian-ag-minister-sees-big-fall-2022-corn-harvest-smaller-area-2023 . According to the Minister of Agriculture, unharvested corn from 2021/22 may have prevented sowing in 2022/23.

absence of other information, I take half the production shortfall and the entirety of the excess consumption as translating directly into reduced exports.

5. The impact of the BSGI

The BSGI is an agreement negotiated in July 2022 between Ukraine, Russia and Turkey and under the auspices of the United Nations to facilitate the export of grains and other commodities from Ukrainian ports and ensure transit out of the conflict zone. The agreement became effective in August 2022 and, after initial implementation problems, volumes picked up from September. Figure 3 charts Ukrainian exports that have taken place under the auspices of the BSGI through to the end of February 2023. The largest tonnages have been in corn (2.5 mmt in the final two months of 2021/22), followed by wheat (1.5 mmt) and oils and oilseeds (1.2 mmt).[22] BSGI shipments of wheat averaged 1.0 mmt per month in the first five months of the 2022/23 crop year and those of corn 1.7 mmt per month. In counterfactual simulation of the absence of the BSGI, I assume that the annual rate of shipments under the initiative to be the same as that in the initial five months of the crop year. This assumption ignores the possibility of seasonality in these shipments. I further assume that Ukrainian grains production and consumption are unaffected by the initiative.

The BSGI agreement was negotiated in July 2022 and was first renewed in November 2022 and then again in mid-March 2023 but currently only until May 2023. I have assumed that the agreement will be further extended at least to the end of the 2022/23 crop year. Table 3 includes (in parentheses) estimates of exports on the "no BSGI" counterfactual. These indicate that, absent the BSGI and on the assumptions made, grain exports from Ukraine would have been close to zero. That assumption may be too strong. Other, more costly, export routes may have been developed and consumption may have been squeezed. However, there is little basis for modeling these hypothetical scenarios.

Figure 6 brings together the estimated export shortfalls. It shows the dramatic impact of the BSGI in the 2022/23 crop year. Projected export shortfalls are seen as declining from the levels projected in May 2022 whereas, without the BSGI, these shortfalls would have increased relative to both the 2021/22 levels and the estimates made in May 2022 when it was still possible to hope that the conflict would be brief.

Table 4 summarizes the resulting conflict-induced export shortfalls. For wheat, these are the same as the overall shortfalls listed in Tables 2 and 3 but for corn the export shortfalls are reduced by half the projected production shortfall to take into account the impact of adverse weather. The March 2023 estimates take the BSGI shipments into account but I also report simulated values on the "no BSGI" scenario (holding production and consumption levels unchanged.[23] Two features stand out. First, the impacts appear

[22] https://www.un.org/en/black-sea-grain-initiative/vessel-movements

[23] The implication is that the excess would have gone into stock in Ukraine. The no-BFGS counterfactual implies a total stock (wheat plus corn) of 43.9 mmt at the end of 2022/23.

larger in corn than in wheat in terms of tonnages but very similar as percentages of world production, which is larger in corn than wheat. Second, the projected impacts on the world wheat market in 2022/23 have tended to decline since the start of the conflict while those in corn have risen despite the BSGI.

Table 4
Estimated Ukrainian conflict-driven export shortfalls

Crop year	WASDE report month	Wheat BSGI	Wheat No BSGI	Corn BSGI	Corn No BSGI
2021/22	March 2022	4.0 (0.6%)		6.0 (0.6%)	
	May 2022	5.0 (0.8%)		10.5 (1.1%)	
	March 2023	5.2 (0.6%)	6.6 (0.8%)	6.5 (0.7%)	9.0 (1.0%)
2022/23	May 2022	1.3 (0.2%)		10.4 (1.4%)	
	March 2023	1.5 (0.2%)	12.6 (1.6%)	1.1 (0.1%)	21.2 (2.7%)

The table reports the estimated export shortfalls (mmt) based on the figures in Table 2 and 3 and using the principles set out in the text. The figures in parentheses translate these quantities into percentages of the world harvest (excluding China) in the May 2021 and May 2022 WASDE projections for 2021/22 and 2022/23 respectively.
Source: Author's calculations using the March 2022, May 2022 and March 2023 WASDE reports.

The size of these shocks can be put in context by comparing them with variability of world production. I measure this variability in two ways – first as the standard deviation of log changes in world (wheat or corn) production, and second as the standard deviation of the WASDE forecast errors. (For 2019/20 this is the log difference between the final WASDE estimate, reported in April 2022, and the initial projection reported in May 2019; and similarly for other years). This second measure is largely measuring weather events while the former measure also includes other sources of variation. Corn harvests are seen as both more variable than wheat harvests, and more difficult to forecast – see Table 5. The Ukraine export shortfalls, reported in Table 4, are small relative to these standard deviations.

It is also worth looking at the estimated (2021/22) and projected (2022/23) Ukrainian export shortfalls in relation to supply shocks elsewhere. I do this for wheat in Figure 7 and corn in Figure 8, measuring the supply shocks as the difference between the March 2023 WASDE estimate or projection and the May 2021 WASDE projection (for 2021/22) and the

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Bloomberg has estimated a total grains storage capacity in the controlled oblasts of Ukraine of 49.8 mmt. https://farmpolicynews.illinois.edu/2022/09/russia-invasion-impacting-ukraines-crop-storage-capacity-while-black-sea-export-deal-in-focus/

May 2022 projection (for 2022/23).[24] The 2021/22 crop year was relatively clement and yielded few major harvest surprises. Instead, major harvest shortfalls are materializing in 2022/23, in particular in the corn market where production appears likely to be adversely affected by dry conditions in Argentina and also eastern Europe (Bulgaria, Hungary and Romania) not offset by increased production elsewhere.

Table 5
Harvest variability

	Wheat	Corn
Year-on-year change	5.80%	8.89%
WASDE forecast error	3.35%	6.83%

The table reports the standard deviation of log changes in world (excluding China) grains production (top row) and of the WASDE forecast errors. Period: 1988/89 – 2020/21.

6. Direct price impacts

The price impacts of these shortfalls are estimated by performing a counterfactual simulation of a small econometric model relating deflated US dollar wheat and corn export prices to the supply-demand balance in each market, as measured by the change in available stocks over the crop year. ("World" stocks exclude stocks held in China because of worries about data reliability and because of large back revisions of the series). The price-stock relationship is modeled as non-linear with the consequence that prices are more responsive to supply shocks when the market is tight (low stock-consumption ratio) than otherwise. The models control for fertilizer prices and for the Brent crude oil price.

A set of unstated price forecasts is implicit in the WASDE supply and demand projections. If prices rise above these forecasts, world grains production will be encouraged and consumption discouraged. As we move forward into the conflict period, actual prices will be above the no conflict prices. This implies that counterfactual production will be lower than foreseen in the WASDE estimates and counterfactual production higher. Short run elasticities are low but, since they apply to the entire world market, these offsetting effects can be substantial. I provide estimates from simple models in the appendix. These suggest consumption elasticities of the order of 0.05 and a production elasticity to the previous year's price of the same order. A large part of the consumption response is seen as being reversed in the following crop year suggesting that any decrease in consumption arises from postponement of consumption. The simulations take these offsetting responses into account.

[24] I have adjusted the WASDE 2022/23 projection for Russian wheat production down by 6.6 mmt on the basis that approximately this quantity is attributable to occupied oblasts of Ukraine.

Details of the model are set out in an appendix. Estimation is either by Ordinary Least Squares (OLS) or Two Stage Least Squares (2SLS), the latter in acknowledgement of the potential endogeneity of the change in world stocks and the fertilizer and crude oil prices. The 2SLS estimates of the wheat price equation show price slightly less sensitive to the stock-consumption ratio relative to the OLS estimates but the two sets of corn price estimates are virtually indistinguishable.

The estimated conflict impacts for the 2021/22 crop year are listed in the upper block of Table 6. These are based on the export shortfalls listed in Table 4 but offset by responses in world production and consumption. The conflict is seen as having raised wheat prices but only by the order of 1½%-2%. The estimated corn price inflation is closer to around 3%. Absent the responses in world consumption, the impact would have been around 0.2% higher.

These impacts are on the 2021/22 crop year average. The conflict started five months into the crop year so the implied impact in the second half of the crop year will have been approaching double these estimates. Furthermore, the BSGI was only operative in the final two months of the crop year. Nevertheless, the actual price increases over the 2020/21 crop year have been much higher – around 29% for wheat and 10% for corn in deflated terms (44% for wheat and 23% for corn in nominal terms).

Table 6
Estimated direct price impacts

Crop year			Wheat		Corn	
			OLS	2SLS	OLS	2SLS
2021-22	March 2022		1.4%	1.1%	3.3%	3.3%
	May 2022		1.8%	1.4%	5.0%	5.0%
	March 2023	with BSGI	2.0%	1.5%	3.2%	3.2%
		without BSGI	2.8%	2.0%	4.8%	4.4%
2022-23	May 2022		-0.2%	-0.3%	2.2%	2.4%
	March 2023	with BSGI	-0.5%	-0.5%	-1.1%	-0.8%
		without BSGI	4.5%	2.8%	11.8%	9.5%

The table reports the estimated price impacts of the conflict-related export shortfalls listed in Table 4. The estimates rely on the WASDE reports in the specified months and the model estimates in Appendix Table A3.

The lower block of the table gives the estimates for the 2022/23 crop year where it is assumed that the BSGI will be operative for the entire year. Table 4 shows the projected export shortfalls to be low so long as the BSGI remains operational. The offsetting effects of changes in world production and consumption are more important in the 2022/23 estimates and become negative with the BSGI in operation as consumption recovers from the 2021/22 levels and production responds to elevated 2021/22 prices.

The table also reports the results of a counterfactual simulation which asks how much prices would have risen absent the BSGI. (This simulation is based on the "no BSGI" market balances reported in Table 4). The BSGI was only operative for the final two months of the 2021/22 crop year so the impact on the crop year average price was relatively small – around ½% - 1% for wheat and 1% - 1½% for corn. The estimated impacts are larger in 2022/23 when it is assumed that the BSGI will have operated for the entire crop year – around 3%-5% in wheat and around 10% - 14% in corn. The greater impact on the corn price is attributable to two factors – the BSGI corn flows are almost twice as large as the wheat flows in volume terms and this is in the context of relatively poor 2022/23 harvests in both Europe and North America.

7. Energy prices and indirect price impacts

The 2022 Ukraine conflict broke out in the economic context of surging commodity prices resulting from the post-Covid expansion of the world economy. High fertilizer prices will have been particularly important for grains producers. Fertilizers provide nitrogen (N), phosphorus (P) and potassium (K) together with smaller amounts of sulfur and magnesium. Depending on price and soil properties, farmers will apply products that incorporate these elements in different proportions. Rosas (2011) reports estimated Cobb-Douglas yield elasticities to fertilizer application. The wheat and corn yield elasticities are reproduced in Table 7 for the United States and the entire world. These estimated elasticities show nitrogen to be the most important additive in both wheat and corn production. Phosphorus is relatively more important for corn than wheat and potassium the least important of the three.

Table 7
Fertilizer yield elasticities

		N	P	K
USA	Wheat	0.17	0.04	0.04
	Corn	0.48	0.17	0.07
World	Wheat	0.74	0.06	0.06
	Corn	0.48	0.17	0.07

Source: Rosas (2011).

Urea, the most important nitrogen-based fertilizer, is manufactured from ammonia which in turn is produced from natural gas, petroleum or, less often, coal. DAP and Triple Superphosphate (TSP) are the most widely-used phosphorus-based fertilizers. DAP, which has the advantage of combining nitrogen and phosphorus, is also manufactured from ammonium. Both urea and DAP prices are therefore driven directly by energy prices. Potash is the main potassium-based fertilizer. Figure 9 charts the deflated urea, DAP and potash prices from 2000/01 to 2022/23.[25] The rises have been more modest than in the previous

[25] Crop year (October-September) averages. 2022/23 figures are October-January.

(2007/08) boom, but as was the case with grains prices, the increases were well underway in 2021 prior to the Ukraine conflict.

Ukraine itself is not a significant producer of fertilizers so there will not have been any direct impact of the conflict on fertilizer prices. Nevertheless, there may have been an indirect impact resulting from the western sanctions imposed on Belarus, which accounts for around 18% of world potash production. Russia is also a major fertilizer producer (N, P, and K). Russian fertilizer exports are exempted from sanctions but may have been affected by the unwillingness of western banks to deal with Russia. The government of the Russian Federation has ceased to publish trade statistics since the start of the conflict making it difficult to analyze the impact of the level of Russian fertilizer exports. According to the CRU Group, these exports declined by 15% in volume terms in 2022 relative to 2021,[26] although higher prices will have entailed a large rise in revenues. Glauber and Laborde (2022) state that the largest volume falls in the early months of the conflict were on Russian exports of ammonia, previously shipped through Ukraine, and Belarus exports of potash, previously shipped through EU ports.

Sanctions imposition led to an immediate 150% increase in the (nominal) price of potash between January and March 2022 and prices have remained at this level since that time. Instead, the prices of other fertilizers only showed a small increase (urea 3%, DAP 34%) and have subsequently dropped back to beneath their pre-conflict levels – see Figure 10. Crude oil prices show the same pattern where the 35% increase in the Brent crude price between January and March 2022 was reversed by September 2022. European natural gas prices, which more than doubled over the summer of 2022 as European nations moved to eliminate Russian imports, have also fallen to below pre-conflict levels.

The grains price model discussed in section 6 and set out in the appendix shows that fertilizer prices have a substantial and immediate impact on wheat and corn prices. This rapid response is in line with the results in Vatsa, Miljkovic and Baek (2023) who report Structural Vector AuroRegression (SVAR) models liking grains prices to fertilizer and natural gas prices. The model used in this paper differs from their model in distinguishing between different types of fertilizer and by acknowledging the possibility of a direct link between crude oil and grains prices.

I implement the “no sanctions” counterfactual though a CVAR linking the DAP and urea prices to the Brent crude and European natural gas prices and a measure of global economic activity. The model is estimated on monthly data from 1991 to the end of 2021. The use of a price-based methodology to construct the “no-sanctions” counterfactual avoids reliance on the absent data on Russian and Belarus exports but runs the risk that unrelated factors may be incorrectly attributed to the conflict.

[26] Private communication.

Petroleum is a feedstock on the production of both urea and DAP and is also used in the transportation of fertilizers. Natural gas is a feedstock for ammonia used in the production of urea. The high cost of liquefying and transporting natural gas implies that there is no single world price for natural gas. The Amsterdam TTF price forms the benchmark for European natural gas commerce. The spike in natural gas prices in the summer of 2022 made it uneconomic to produce ammonium in western Europe with a resulting impact on the world price of urea. I measure economic activity using the Kilian (2009, 2019) Index of Global Real Economic Activity (IGREA) index.[27] See Kilian and Zhou (2018) for discussion of the merits of the IGREA index in commodity modeling. The CVAR model is discussed in the model appendix.

The “no sanctions” counterfactual is generated by comparing realized DAP and urea prices with the forecasts generated by the model starting from the histories of the five variables up to and including their January 2022 values. The CVAR model, which has three cointegrating vectors, can be normalized as showing the two fertilizer prices as having equilibrium relationships with the two energy prices – DAP with the Brent crude price and natural gas with the crude oil and natural gas prices. In addition, the natural gas price is driven by the crude oil price in the long run. Since the IGREA is defined so as to be stationary, this results in the fertilizer and energy prices as sharing a single common trend.

In less technical terms, the model generates price paths that are contingent on crude oil prices which determine the single common trend. Changes in the Brent crude price are essentially unforecastable implying that the same is true of the long term levels of the fertilizer and natural gas prices. Nevertheless, there is short term forecastability in natural gas and fertilizer prices as these converge back to trend levels. Figure 11 charts the actual and “no war” counterfactual crude oil and natural gas prices and Figure 12 does the same for the DAP and urea prices. By construction, the counterfactual Brent crude price is projected as near constant at its pre-war level but this should not be taken as a forecast.[28]

Comparison of the actual price paths with the January 2022 projections suggest that the conflict may have raised crude oil prices by around $20/bbl in the spring and early summer of 2002 but that this divergence was eliminated by the end of the summer. Instead, the ”no war” natural gas price is sees as steadily declining over 2022 while the actual price rose by around 42% in March 2022 following the start of the conflict and by a staggering 125% over the summer of 2022 as European countries moved to eliminate imports of Russian gas. The fertilizer counterfactuals show both DAP and urea prices declining steadily through the year from their elevated 2021 levels but with the urea price declining more rapidly given its dependence on natural gas.

[27] Source: Federal Reserve Bank of Dallas.

[28] Small over-the horizon variations in the Brent crude projection are due to responses to the IGREA which shows a degree of autocorrelation.

Table 8 reports the overall inflation of the crude oil, natural gas and fertilizer prices over the final seven months of the 2021/22 crop year and the initial four months of 2022/23. These are the price increases which enter into calculation of the indirect impact of the Ukraine conflict on grains prices. I use these numbers in conjunction with the grains price model discussed in section 5 to estimate the indirect impact of the Ukraine conflict on wheat and corn prices. These estimates are reported in Table 9.

Table 8
Estimated impact of the Ukraine conflict on energy and fertilizer prices

	Brent crude	Natural gas	DAP	Urea
March – September 2022	2.1%	19.8%	2.3%	1.7%
October 2022 – January 2023	-1.8%	71.2%	1.0%	2.1%

The table reports the estimated inflation of energy and fertilizer prices resulting from the Ukraine conflict over the specified period.

The estimated indirect impacts of the conflict were of similar magnitude are larger for corn than wheat as the consequence of the reliance of wheat on urea, the price of which depends on the natural gas price. The indirect impacts on the wheat price are around half of the direct impacts while for corn the direct impacts dominate. The conflict-related crude oil price inflations are negligible in 2022/23 so the indirect impact of higher oil prices comes almost entirely through higher fertilizer prices. The overall picture is therefore broadly similar to that presented in Table 6.

Table 9
Estimated direct and indirect price impacts

Crop year			Wheat OLS	Wheat 2SLS	Corn OLS	Corn 2SLS
2021-22	Direct effect	with BSGI	2.0%	1.5%	3.2%	3.2%
		without BSGI	2.8%	2.0%	4.8%	4.4%
	Brent crude price		0.1%	0.1%	0.2%	0.2%
	Fertilizer prices		0.9%	1.1%	1.1%	0.8%
	Total indirect effect		1.0%	1.2%	1.2%	1.0%
	Direct + indirect effect	with BSGI	3.0%	2.7%	4.4%	4.2%
		without BSGI	3.9%	3.1%	6.0%	5.0%
2022-23	Direct effect	with BSGI	-0.5%	-0.5%	-1.1%	-0.8%
		without BSGI	4.5%	2.8%	11.8%	9.5%
	Brent crude price		0.0%	0.0%	-0.1%	-0.1%
	Fertilizer prices		1.5%	1.7%	0.6%	0.7%
	Total indirect effect		1.5%	1.7%	0.5%	0.7%
	Direct + indirect effect	with BSGI	1.0%	1.2%	-0.5%	0.0%
		without BSGI	6.0%	4.5%	12.4%	10.2%

The table repeats the estimated direct price impacts of the conflict from Table 5 and adds the estimated indirect estimates coming through crude oil and fertilizer prices. Components may fail to sum to the aggregates because of rounding.

The estimates reported in Tables 8 and 9 are reliant on the common trend in the energy and fertilizer prices which are determined by the forecast path in the Brent crude price. The estimated conflict impacts would have been much higher if, absent the conflict and the western responses, the oil price had fallen sharply in the same way as has happened with metals prices. The estimated indirect effects tabulated in Table 9 should therefore be seen as more conjectural than the direct effects which are based on the comparison of actual production and export levels with official projections.

There were widespread fears at the outbreak of the conflict that limitations to Ukraine's ability to produce and export would result in a major food price spike. These fears have not materialized. This is mainly due to the success of the BSGI which has ensured that grain produced in Ukraine is delivered to consumers. The main reason that grains prices were high in the 2021/22 crop year is that, along with the prices of other primary materials, they had risen in the 2020/21 crop year prior to the Ukraine conflict. The conflict led to further upward pressure in the spring of 2022 but has subsequently retarded the decline to more normal levels, rather than further raised prices.

The open question is therefore why grains prices rose so sharply over the Covid recovery period in the 2020/21 crop year. The model set out in the appendix points the finger at the rise in fertilizer prices that took place in the post-Covid rebound. Fertilizer prices rose sharply in this rebound – see the left column of Table 10. The model estimates reported in the appendix show that these price rises translate into large increases in wheat and corn prices. Table 10 lists the price increases attributable to each of these components. The analysis is incomplete since supply and demand factors will also have been important – the wheat market was supplied over this period but the corn market became tight in 2021. Nevertheless, comparison of the total energy and fertilizer impact with the actual rise in prices indicates that fertilizer prices may have been the link whereby the post-Covid demand shock translated into a cost shock in the grains markets.

Table 10
Price changes attributable to energy and fertilizer prices, calendar year 2021 over 2020

	Price rise 2021 over 2020	Wheat		Corn	
		OLS	2SLS	OLS	2SLS
Brent crude	42.2%	2.2%	1.6%	3.2%	3.7%
DAP	56.7%	13.1%	15.1%	26.0%	20.0%
Urea	65.1%	15.0%	17.4%	0.0%	0.0%
Total energy & fertilizers		30.3%	34.1%	29.2%	23.6%
Price rise 2021 over 2020		22.2%		36.6%	

Column 1 of the table lists the log price changes of Brent crude oil, DAP and urea over the calendar year 2021 relative to 2020. The remaining columns report the estimated impact of these changes on wheat and corn prices. The final row lists the actual log price change over the same period.

8. Concluding remarks

Ukraine is a major producer of both wheat and corn. The Russian invasion of Ukraine that started in February 2022 led to widespread concern that this could limit the availability of grains on world markets and lead to increases in grains prices on world markets. Grains price were already high in February 2022 having risen steadily through the 2021 post-Covid recovery. They continued to rise through the spring of 2022 but subsequently stabilized and, at the time of writing (February 2023) have fallen back to their pre-conflict levels. Nevertheless, the conflict remains as far as ever from resolution.

This paper provides this analysis through a combination of event study (before-after) analysis of projections of the physical grains balance in Ukraine in conjunction with an econometric implementation of the competitive storage model to translate export shortfalls into price impacts. The modeling exploits the USDA's monthly WASDE projections of grains production, consumption and exports. The revisions to these projections over the conflict period allow inference on the extent to which USDA analysts saw the conflict as likely to restrict Ukrainian production and exports of wheat and corn.

The main conclusions are as follows:

- The supply shocks induced by the Ukraine conflict have been relatively modest as a percentage of world consumption. In particular, dry weather conditions, both in Argentina and Eastern Europe, have had a larger impact on availability in the corn market.
- The conflict supply shocks appear to have directly raised crop year average wheat prices by 2% - 3% and corn prices by 4% in the 2021/22 crop year. Because the shock arose four months into the crop year the price rises in the second half of the crop year will have been around 50% greater than these figures.
- These direct impacts are seen to vanish in the 2022/23 crop year so long as the Black Sea Grain Initiative (BSGI) remains operational. The BSGI ensures that the grain that Ukraine produces reaches consumer markets albeit at a greater cost than prior to the conflict. Furthermore, the elevated 2021/22 prices will have generated a mild stimulus to grains production outside Ukraine and resulted in the postponement of some purchases into the 2022/23 crop year with the consequence that prices may end up marginally lower than on the no war counterfactual.
- The BSGI has been and remains crucial in limiting the scale of grains price increases, particularly in the corn market where BSGI shipments have been larger and where poor harvests elsewhere in the world have resulted in tight market conditions. The BSGI was only operational for the final two months of the 2021/22 crop year and so had a limited impact on the crop year average price – ½% - 1% in wheat and around 1½% in corn. The impacts will be proportionately larger in the 2022/23 crop year (3% - 5% in wheat, but 10% to 14% in corn) provided the agreement continues to remain in force.

- The conflict has also had indirect effects resulting from western sanctions and other actions aimed at limiting Russia's export revenues from crude oil and natural gas exports. These actions raised the price of natural gas on the European market and, to a lesser extent, the world petroleum price. These price increases have directly increased fertilizer prices which rapidly feed through into grains prices. have estimated these impacts at around 1% for both wheat and corn and both in 2021/22, but up to 1½% for corn in 2022/23. These estimates should be taken as less secure than the estimated direct impacts since the counterfactual is less clear.
- On this basis, I conclude that, taking these indirect effects into account, the conflict raised wheat prices by 3% - 4% and corn prices by 5% - 5½% in the 2021/22 crop year. So long as the BSGI remains operative, the impact of the conflict on the world grains market will be negligible (less than 1%) in the current (2022/23) crop year. This is not minimize the impact within Ukraine where the conflict has led to loss of wheat production to Russia in the occupied oblasts and raised both production and logistics costs within the controlled areas.

The price of hard wheat peaked at $522/ton in May 2022, 92% higher than the price of $272/ton in October 2020 at the start of the 2020/21 crop year; the corresponding figures for corn are $348/ton in April 2022, 86% higher than the October 2020 price of $187/ton. The increases attributable to the Ukraine conflict only account for a small proportion of this overall rise. The analysis in this paper suggests that the major cause of high grains prices in the 2021/22 crop year was the post-Covid expansion in the world economy acting through the channel of elevated fertilizer prices.

Appendix

The grains model relates crop year averages of the logarithms of the deflated US dollar export prices of hard wheat (wheat, *pw*) and maize (corn, *pc*) to the change in world stocks over the crop year and to the levels of fertilizer prices. I model the corn price as depending on the price of DAP (*pd*) whereas I model wheat as depending on an index (*pf*) which gives equal weight to the DAP price and the urea price (*pu*). Deflation is by the US Producer Price Index (PPI). Estimation is over the common sample 1987/88 – 2020/21 (38 observations). Variable definitions are provided at the end of this appendix.

Standard tests indicate that the wheat price can be regarded as stationary over the estimation sample (ADF(1) = -3.19 relative to the 5% critical value of -2.95) while the failure to reject non-stationarity for the corn price is relatively marginal (ADF(1) = -2.75). Fertilizer prices rose sharply around 2007 and, despite some decline, have not returned to their original levels. The same non-stationarity yields a statistic of ADF(3) = -1.61. In the grains price regressions reported below, I replace the logarithm of the DAP and urea prices by their departures from a cubic trend. Preliminary regressions indicate that it is these deviations and not the fertilizer price trends that are associated with grains prices. ADF(3) values are 2.68 for DAP, -2.66 for urea, and -2.62 for the index, all relative to a critical value of -3.55.

The grains model comprises equations for the two grains prices. I use the same specification for the wheat and corn prices and ignore factors (such as the role of ethanol) that are specific to one or other grain The equations relate the price to its value in the previous crop year, the market balance, the fertilizer price and the Brent crude oil price (*pbc*). I measure the market balance by the change in ratio of end-crop year stocks (*sw* and *sc* for wheat and corn respectively) to the trend in world consumption. The stock-consumption ratios enter the equations as reciprocals making the price responsive to shocks when the market is tight (the stock-consumption ratio is low). The lagged dependent variable arises because time averages of continuous price diffusions will be positively autocorrelated (Working, 1960). The inverse stock-consumption ratio and the fertilizer and Brent crude prices are treated as endogenous. The equations are:

$$\begin{aligned} \ln pw_t &= \beta_0^w + \beta_1^w \ln pw_{t-1} + \beta_2^w \Delta\left(sw_t^{-1}\right) + \beta_3^w \ln pf_t + \beta_4^w \ln pbc_t + u_t^w \\ \ln pc_t &= \beta_0^c + \beta_1^c \ln pw_{t-1} + \beta_2^c \Delta\left(sc_t^{-1}\right) + \beta_3^c \ln pd_t + \beta_4^c \ln pbc_t + u_t^d \end{aligned} \qquad \text{(A1)}$$

Table A1 reports estimates of the two grains price equations. Columns 1 and 2 report OLS estimates of equation (A1) and columns 3 and 4 report the corresponding 2SLS estimates. The OLS equations fit well and have well-determined coefficients. Since there is no evidence of either residual autocorrelation or heteroscedasticity, I report uncorrected coefficient standard errors. Coefficient magnitudes are generally similar across the two sets of equations. The 2SLS estimates are very similar but show a reduced sensitivity of wheat prices to stock changes.[29]

Table A1 Equation estimates					
		OLS		2SLS	
		Wheat	Corn	Wheat	Corn
	Dependent variable	lnpw_t	lnpc_t	lnpw_t	lnpc_t
β_0	*Intercept*	2.939*** (0.556)	2.287*** (0.383)	3.288*** (0.725)	2.050*** (0.471)
β_1	wheat: lnpw_{t-1} corn: lnpc_{t-1}	0.415*** (0.101)	0.493*** (0.077)	0.360*** (0.129)	0.532*** (0.091)
β_2	wheat: $\Delta\left(sw_t^{-1}\right)$ corn: $\Delta\left(sc_t^{-1}\right)$	1.364*** (0.340)	0.568*** (0.090)	1.038** (0.500)	0.594*** (0.186)
β_3	wheat: lnpf_t corn: lnpd_t	0.462*** (0.095)	0.459*** (0.074)	0.534*** (0.153)	0.352** (0.123)
β_4	lnpbc_t	0.051 (0.036)	0.076** (0.033)	0.037 (0.041)	0.087** (0.038)
R^2		0.818	0.873	0.810	0.865
standard error		0.097	0.088	0.099	0.091
Correlation of residuals		0.233		0.251	
AR(2)	$F_{2,27}$	0.692 [0.509]	0.582 [0.567]	0.347 [0.710]	0.956 [0.397]
Heteroscedasticity	$F_{8,25}$	0.317 [0.952]	1.873 [0.110]	0.297 [0.960]	1.708 [0.146]
Instrument validity	χ_4^2	-	-	6.14 [0.189]	1.63 [0.653]

Sample: stated 1987/88 to 2020/21. Coefficient standard errors (no adjustment) in (.) parentheses; tail probabilities in [.] parentheses.
*,**,***: significantly different from zero at the 10%, 5% and 1% levels respectively.
The IV estimates regard $\Delta\left(sw_t^{-1}\right)$, $\Delta\left(sc_t^{-1}\right)$, ln$pd_t$, and ln$pf_t$ as endogenous.
Instruments: sw_t^{proj} and sw_{t-1} (only in the corn price equation, sc_t^{proj} and sc_{t-1} in the wheat price equation), plus lnpf_{t-1}, lnpbc_{t-1}, $igrea_t$, $igrea_{t-1}$ and Δlngdp_t.

There is only weak evidence for a direct impact of the Brent crude price on grains prices given that the equations control for fertilizer prices. This is in line with the argument in Gilbert and Mugera (2019) who infer from US input-output tables that the input share of

[29] I report R^2 statistics for the 2SLS estimates to provide an indication of fit even though they lack a clear interpretation. They are calculated as the squared correlation of the actuals and the fitted values.

petroleum refining in US grains production differs little from that of the remainder of the economy implying that oil prices should have a similar impact on the numerator and denominator of deflated grains prices. However, Gilbert and Mugera (2019) also show that the crude oil price has pulled up the corn price in periods in which there has been spare ethanol refining capacity in the US. Despite the weak evidence for a direct link between the crude oil and the wheat price, I have chosen to maintain the same specification in both equations.

The simulations listed in the main paper also require estimates of short run consumption and production elasticities. Since these simulations only extend forward for a single crop year, I adopt a simple modeling procedure by looking at deviations from estimated cubic trends. For consumption, I estimate

$$\ln cx_t = \gamma_{x0} \ln px_t + \gamma_{x1} \ln px_{t-1} + \gamma_{x2} + \gamma_{x3} t + \gamma_{x4} t^2 + \gamma_{x5} t^3 + \varepsilon_{xt} \quad (x = w, c) \tag{A2}$$

$$\ln qx_t = \delta_{x0} \ln qx_{t-1} + \delta_{x1} \ln px_{t-1} + \delta_{x2} + \delta_{x3} t + \delta_{x4} t^2 + \delta_{x5} t^3 + \nu_{xt} \quad (x = w, c) \tag{A3}$$

where *cw* and *cc* are world (excluding China) consumption of wheat and corn respectively, *qw* and *qc* are the corresponding production levels, and ε_w, ε_c, ν_w, and ν_c are disturbances. Equations (A2) are estimated by both OLS and 2SLS; equation (A3) by OLS. Estimation results for the elasticities are reported in Table A2.

Table A2
Estimated elasticities for world consumption and production

		Wheat		Corn	
		OLS	2SLS	OLS	2SLS
Consumption	Current price	-0.064***	-0.071**	-0.031	-0.054
	γ_{0w} , γ_{0c}	(0.018)	(0.030)	(0.025)	(0.048)
	Lagged price	0.036*	0.037	0.039	0.052
	γ_{1w} , γ_{1c}	(0.019)	(0.022)	(0.025)	(0.034)
Production	Lagged price	0.071	-	0.051	-
	δ_{1w} , δ_{1c}	(0.043)		(0.045)	

The table lists the estimated coefficients and standard errors from regression of the logs of world consumption and production on current (only consumption), and lagged log prices. The lagged dependent variable (only production) and a cubic trend. Sample 1987/88 to 2020/21.

I now turn to the fertilizer price model. This is a five variable monthly CVAR linking the logs of the deflated urea, DAP, Brent crude and European natural gas prices and the Kilian (2009, 2019) Index of Global Real Economic Activity (IGREA) index.[30] Estimation is from April 1991 to December 2012. The IGREA is constructed to be stationary but the ADF test fails to

[30] Source: Federal Reserve Bank of Dallas.

reject non-stationary for all four price series.[31] The CVAR therefore models the prices as first differences and IGREA as a level.

Given that IGREA is stationary, the cointegration analysis just involves the four prices. The Johansen (1991) trace cointegration test finds three cointegrating vectors – the hypothesis $rank\left(\alpha\beta'\right)\leq 2$ is rejected at the 5% level. Without loss of generality, I can normalize the β matrix such that the three cointegrating vectors are normalized on the DAP, urea and natural gas prices respectively:

$$\beta=\begin{pmatrix}-1 & 0 & \beta_{gd}\\ 0 & -1 & \beta_{gu}\\ \beta_{dg} & \beta_{ug} & -1\\ \beta_{db} & \beta_{ub} & \beta_{gb}\end{pmatrix} \tag{A4}$$

where the subscripts *d*, *u*, *g*, and *b* refer respectively to the price ln*DAP*, ln*urea*, ln*ng* and ln*Brent*. I also impose two following further restrictions on β:

- $\beta_{gd} = \beta_{gu} = 0$ implying that fertilizer prices do not enter the long run relationship between crude oil and natural gas prices;
- $\beta_{dg} = 0$ implying that the DAP price is unaffected by the natural gas price in the long run. (Here, unrestricted estimation yields an implausible but statistically insignificant negative coefficient).

I restrict the α matrix as

$$\alpha=\begin{pmatrix}\alpha_{dd} & \alpha_{ud} & 0\\ \alpha_{du} & \alpha_{uu} & 0\\ \alpha_{dg} & \alpha_{ug} & \alpha_{gg}\\ 0 & 0 & \alpha_{gb}\end{pmatrix} \tag{A5}$$

This imposes a total of three restrictions on $\alpha\beta'$. The likelihood ratio test of these restrictions yields a value of χ_3^2 = 0.25 with tail probability 0.969. The estimated matrices are reported in Table A3. The estimated coefficients show a well-determined link between crude oil prices and both DAP and urea prices plus a weaker and only marginally statistically significant link between the European natural gas price and the urea prices.

On this basis, I estimate a CVAR(3) for the four prices and the IGREA. I take the Brent crude price as strongly exogenous with respect to the two fertilizer prices and the natural gas price. I also suppose that the DAP price is unaffected by natural gas prices. Estimation

[31] IGREA: ADF(2) = -3.31. Brent crude: ADF(2) = -1.96. Natural gas: ADF(3) = -2.22. Urea: ADF(2) = -2.37. DAP: ADF(1) = -2.71. The 5% critical value is -2.87 in all five cases.

results are reported in Table A4. The likelihood ratio test of the coefficient restrictions yields a value of χ^2_{20} = 24.00 with tail probability 0.242.

Table A3
Estimated cointegrating vectors and adjustment coefficients

	β			α		
	ln*DAP*	ln*urea*	ln*ng*	ln*DAP*	ln*urea*	ln*ng*
ln*DAP*	-1.000	0.000	0.000	0.068*** (0.023)	-0.009 (0.028)	0.000
ln*urea*	0.000	-1.000	0.000	-0.097 (0.039)	0.174*** (0.030)	0.000
ln*ng*	0.000	0.224* (0.121)	-1.000	0.000	-0.014 (0.020)	0.021 (0.014)
ln*Brent*	0.709*** (0.145)	0.579*** (0.084)	1.602*** (0.287)	-0.014 (0.031)	0.000	-0.044*** (0.014)

The table reports the estimated β cointegrating vectors and α adjustment coefficients in the Johansen (1991) model. Sample: April 1991 – December 2012. Standard errors in parentheses. *,**,***: significantly different from zero at the 10%, 5% and 1% levels respectively.

Rather than attempting to interpret the estimated CVAR coefficients, it is preferable to look at impulse response functions. Figure 13 shows the responses of the DAP price to one standard error shocks in each of the CVAR variables.[32] Figure 14, drawn to the same scale, shows the response functions for the urea prices.

- Shocks to the urea price decay very quickly. A one standard error (10.8%) shock has peak effect in the following month but the effect is halved after three months and dissipates completely after a further nine months. Shocks to the DAP price are more persistent. A one standard error (5.6%) shock has maximum impact in the third month and takes a further year to halve.
- Shocks to the urea price appear to have a negligible impact on the DAP price while shocks to the DAP price have a substantial impact on the urea price peaking after ten months. This finding is at variance with the fact that the urea market has much greater liquidity than the DAP market.
- In line with the specification of the β matrix in equation (A2), shocks to the natural gas price have a negligible impact on the DAP price but a substantial impact on the urea price peaking after three months.

[32] The CVAR residuals exhibit low cross-equation correlations so little would be gained from orthogonalization. (The highest correlation, 0.345, is between the DAP and urea residuals. The remaining correlations are less than 0.21).

- The price of crude oil has a persistent impact on both the DAP and the urea prices. A one standard error shock (8.6%) raises DAP prices by 4.5% (53% pass-through) and urea prices by 6.8% (79% pass-through).

Table A4
CVAR estimates

	$\Delta \ln DAP_t$	$\Delta \ln urea_t$	$\Delta \ln ngas_t$	$\Delta \ln Brent_t$	$IGREA_t$
Intercept	0.099** (0.040)	0.279*** (0.077)	-0.269*** (0.079)	0.001 (0.004)	0.000 (0.001)
$\Delta \ln DAP_{t-1}$	0.427*** (0.056)	0.029 (0.108)	0.167** (0.069)	-	-0.019 (0.017)
$\Delta \ln DAP_{t-2}$	-0.060 (0.060)	0.047 (0.117)	-0.177** (0.075)	-	0.043** (0.018)
$\Delta \ln DAP_{t-3}$	-0.033 (0.056)	-0.143 (0.109)	0.130* (0.070)	-	0.013 (0.017)
$\Delta \ln urea_{t-1}$	0.018 (0.029)	0.203*** (0.057)	-0.095*** (0.037)	-	0.008 (0.009)
$\Delta \ln urea_{t-2}$	0.044 (0.029)	-0.054 (0.057)	0.069* (0.036)	-	-0.002 (0.009)
$\Delta \ln urea_{t-3}$	-0.034 (0.030)	0.017 (0.058)	-0.043 (0.037)	-	-0.015* (0.009)
$\Delta \ln ngas_{t-1}$	-	0.031 (0.077)	0.301*** (0.052)	-	-0.017 (0.013)
$\Delta \ln ngas_{t-2}$	-	0.158* (0.083)	0.001 (0.056)	-	-0.005 (0.014)
$\Delta \ln ngas_{t-3}$	-	-0.032 (0.079)	0.216*** (0.053)	-	-0.014 (0.013)
$\Delta \ln Brent_{t-1}$	0.048 (0.035)	0.034 (0.069)	0.119*** (0.044)	0.228*** (0.053)	0.040*** (0.011)
$\Delta \ln Brent_{t-2}$	0.006 (0.037)	0.039 (0.071)	0.045 (0.045)	-0.138** (0.055)	0.019** (0.011)
$\Delta \ln Brent_{t-3}$	0.000 (0.036)	-0.083 (0.071)	0.098** (0.045)	-0.074 (0.054)	-0.008 (0.011)
$IGREA_{t-1}$	0.412** (0.174)	1.131*** (0.341)	0.006 (0.218)	0.563** (0.261)	1.184*** (0.054)
$IGREA_{t-2}$	-0.192 (0.265)	-1.231** (0.515)	0.632* (0.328)	-0.047 (0.398)	-0.318*** (0.082)
$IGREA_{t-3}$	-0.109 (0.175)	0.292 (0.341)	-0.605*** (0.217)	-0.470* (0.262)	0.082 (0.054)
$cv_{1,t-1}$	-0.024* (0.014)	0.069*** (0.026)	0.043** (0.019)	-	-
$cv_{2,t-1}$	-0.010 (0.017)	-0.177*** (0.033)	0.011 (0.021)	-	-
$cv_{3,t-1}$	-	-	-0.025*** (0.009)	-	-
s.e.	0.0561	0.1082	0.0687	0.0860	0.0172
R^2	0.280	0.177	0.322	0.094	0.928

The table reports the estimates of the estimated CVAR linking fertilizer prices to energy prices and global economic activity. Sample May 1991 – December 2021. Estimation by FIML.
R^2 statistics are calculated as the squared correlation between the actual and fitted values.
cv_1, cv_2 and cv_3 refer to the cointegrating vectors defined by the respective β coefficients reported in Table A3. Standard errors in parentheses.
*,**,***: significantly different from zero at the 10%, 5% and 1% levels respectively.

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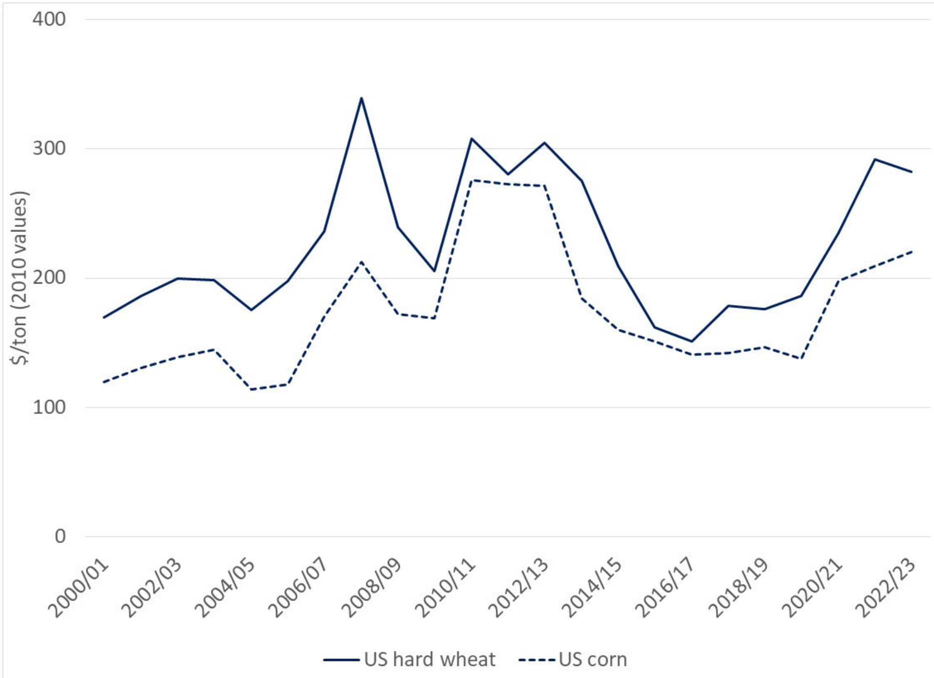

Figure 1: Grains prices, 2000/01 – 2022/23

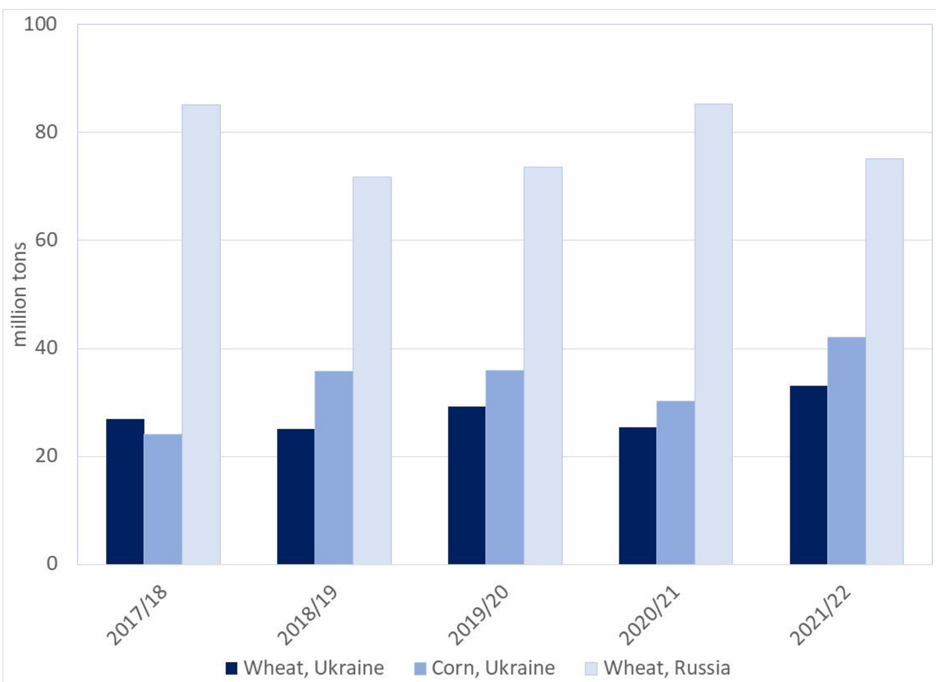

Figure 2: Ukrainian and Russian harvests, 2017/18 – 2021/22, plus 2022/23 projection

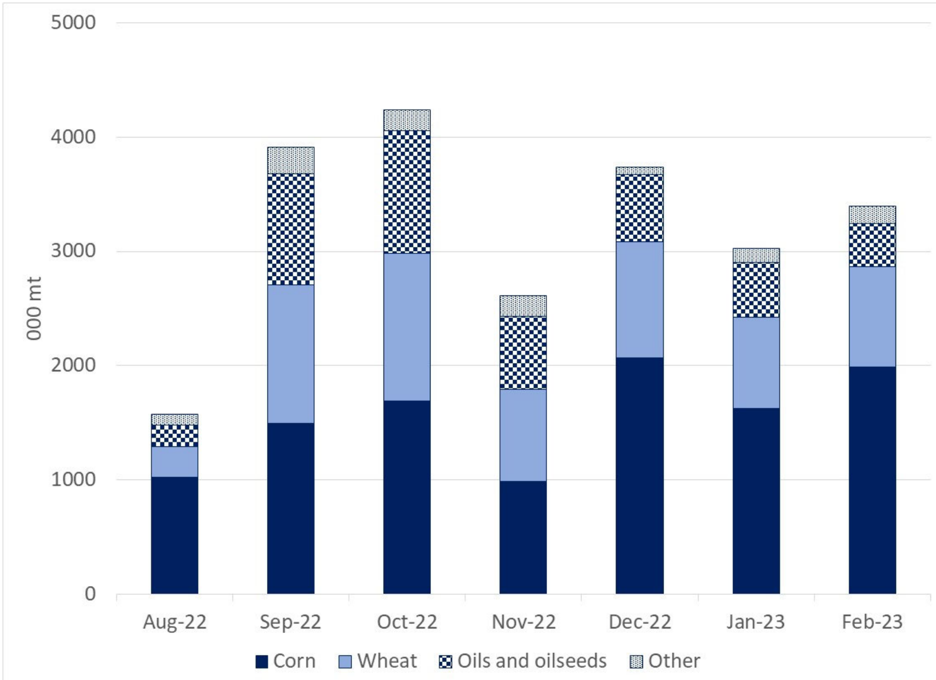

Figure 3: Shipments under the auspices of the Black Sea Grain Initiative, 2022-23

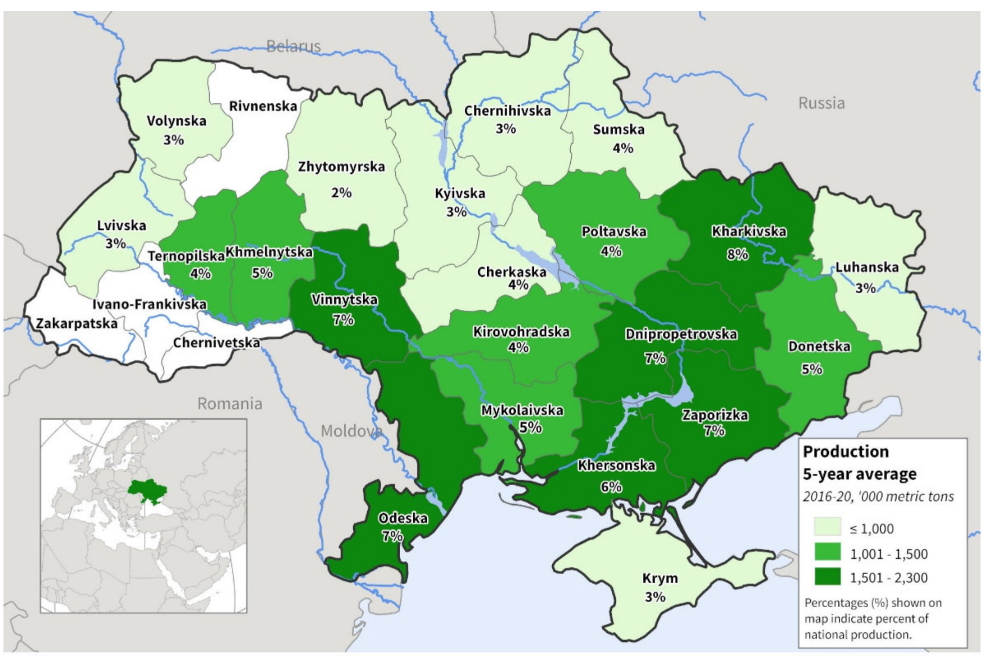

Figure 4: Regional distribution of Ukrainian wheat production, 2016-20

Figure 5: Regional distribution of Ukrainian corn production, 2016-20

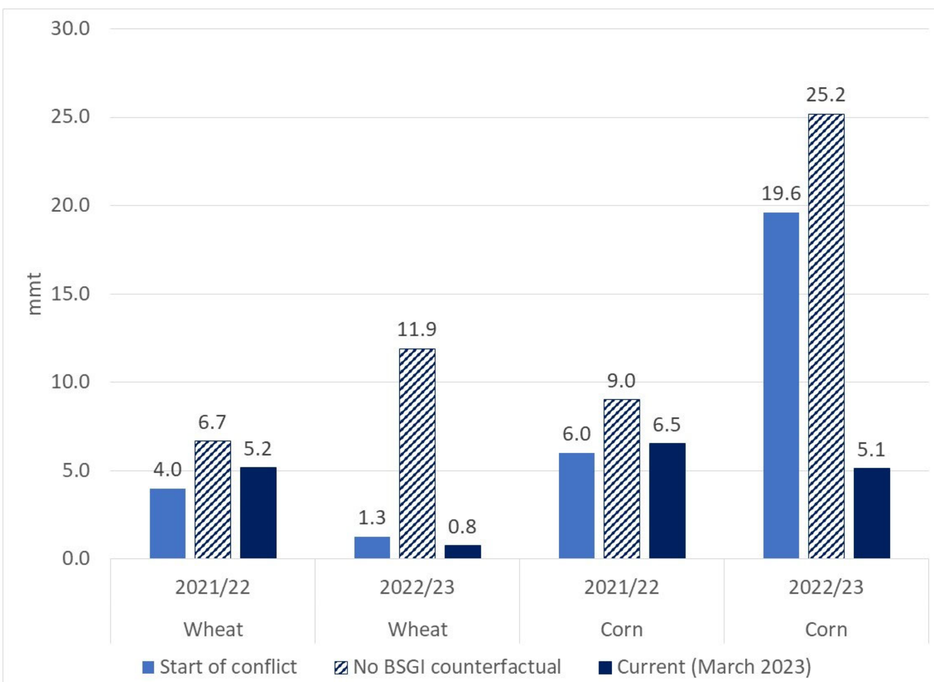

Figure 6: Estimated export shortfalls

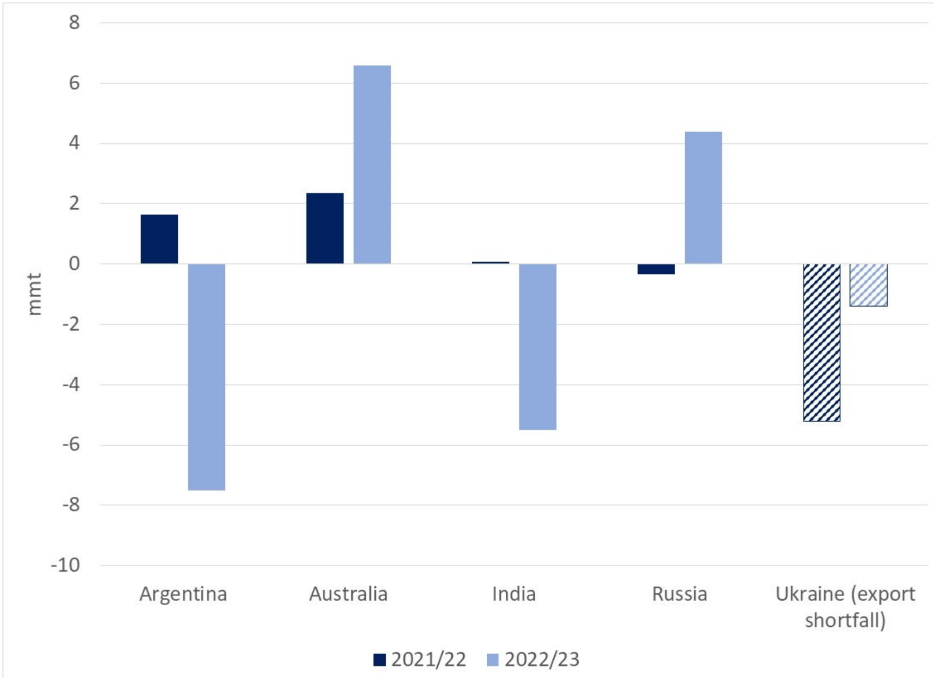

Figure 7: Major wheat production shocks, 2021/22 and (projected) 2022/23

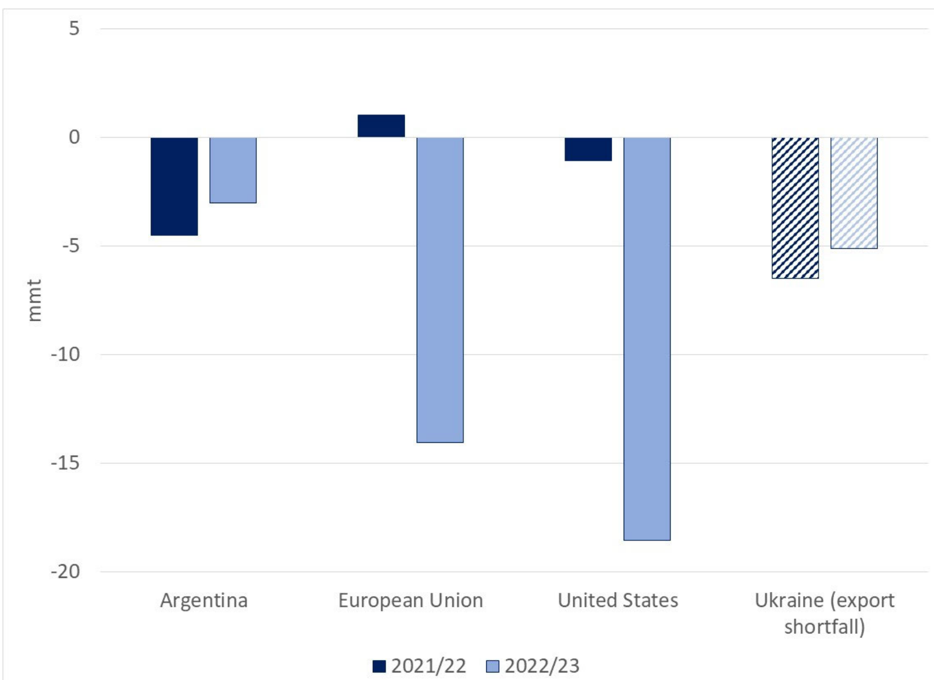

Figure 8: Major corn production shocks, 2021/22 and (projected) 2022/23

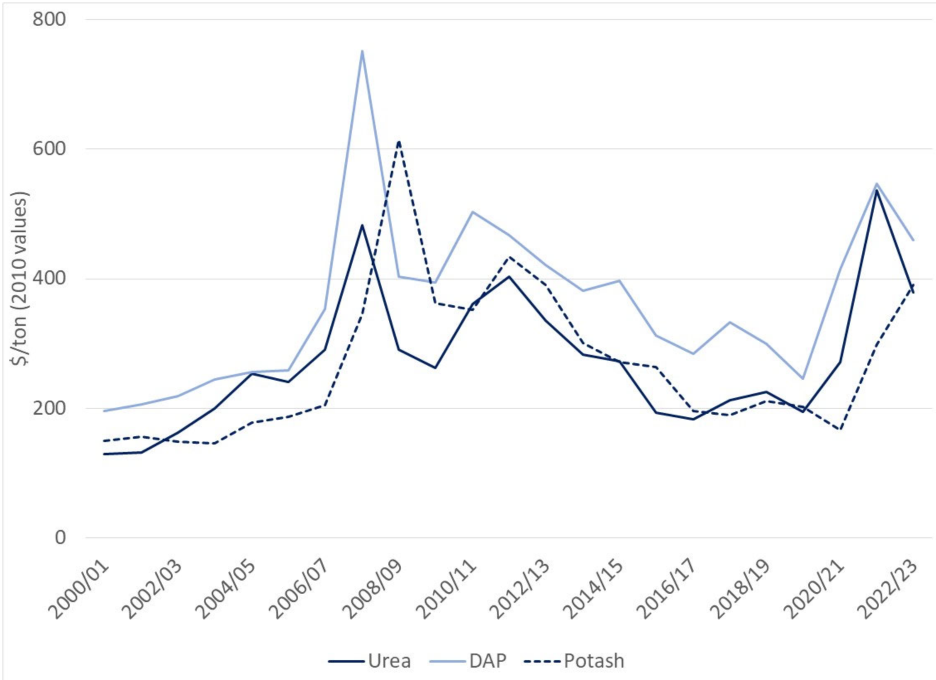

Figure 9: Fertilizer prices, 2000/01 – 2022/23

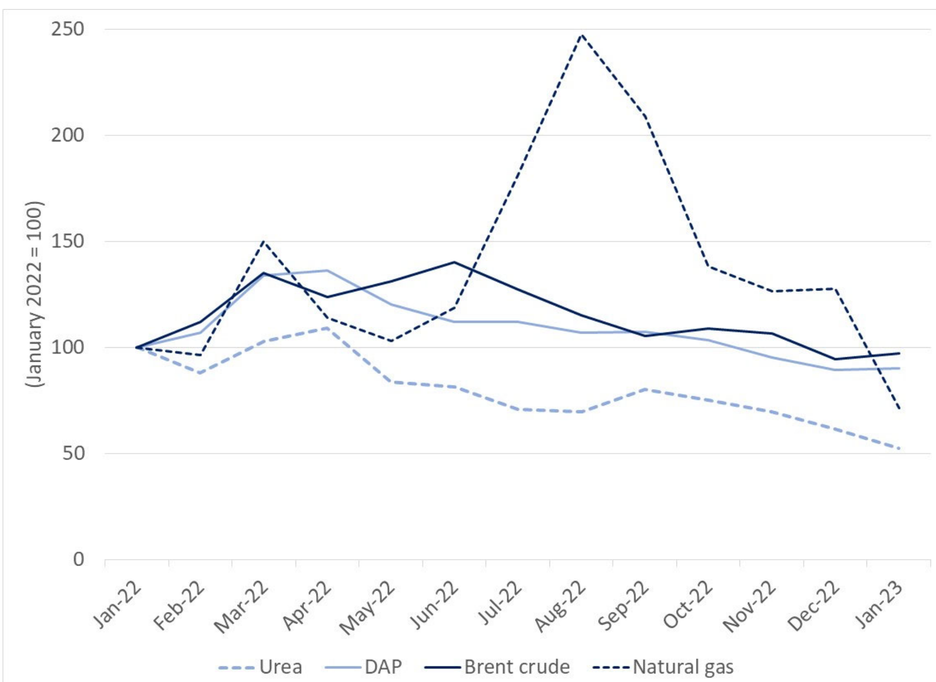

Figure 10: Energy and fertilizer prices, January 2022 –January 2023

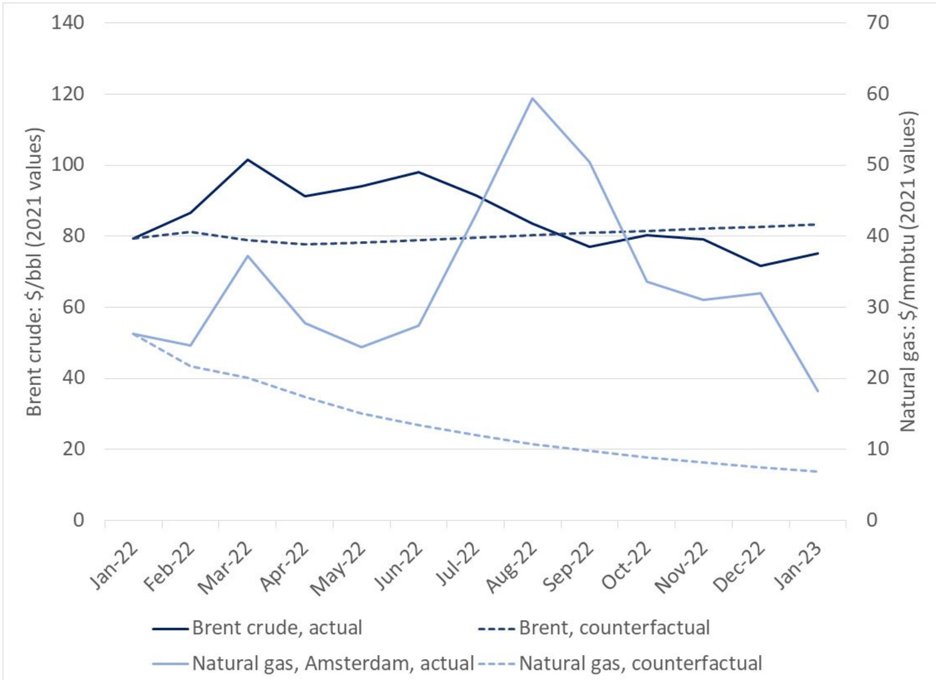

Figure 11: Actual and counterfactual energy prices, January 2022 –January 2023

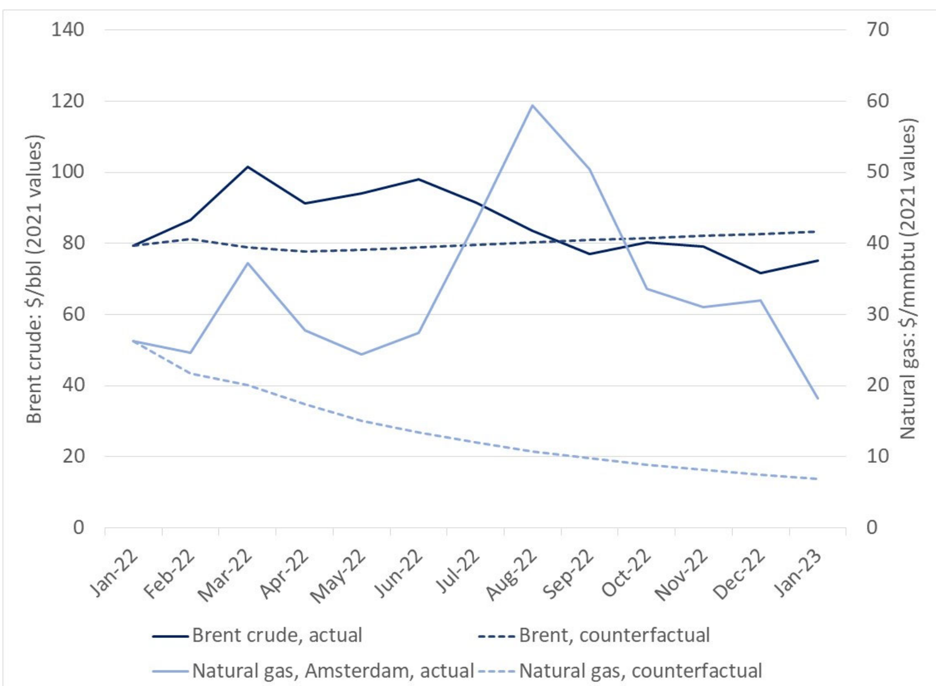

Figure 12: Actual and counterfactual fertilizer prices, January 2022 –January 2023

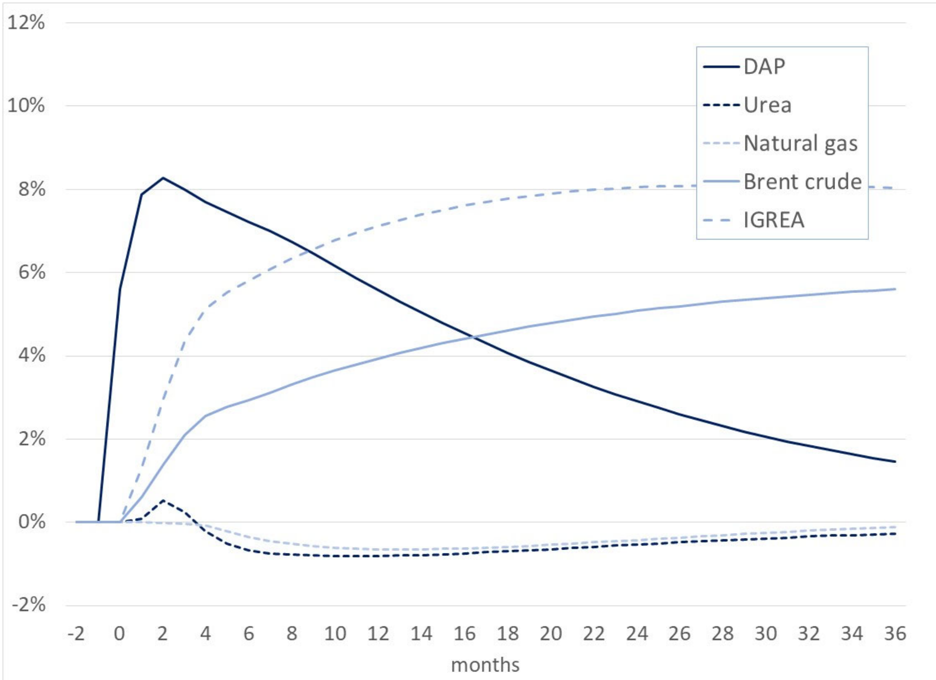

Figure 13: Impulse response functions for the DAP price from 1 standard error shocks to the CVAR variables

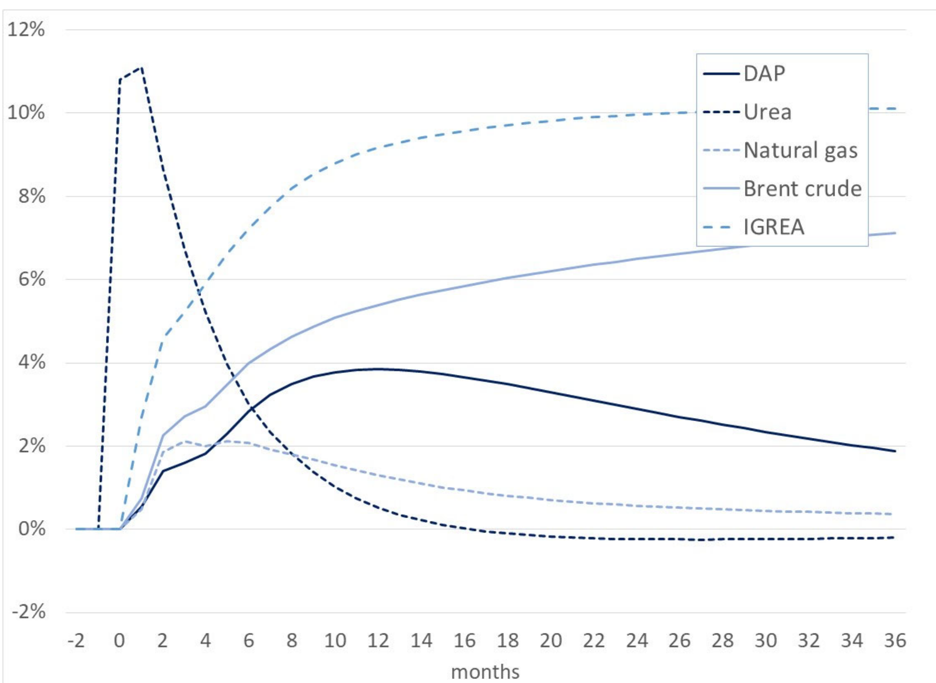

Figure 14: Impulse response functions for the urea price from 1 standard error shocks to the CVAR variables