cBrief 3: Weaponizing Wheat
Moscow's Menace to Food Security in 2023

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Executive Summary

Food insecurity was top-of-mind throughout 2022. What about 2023? There is no end in sight to the armed conflict in Ukraine. Both Ukraine and the Russian Federation were major suppliers of wheat to world market before the invasion. What's at stake if Moscow seeks to weaponize wheat exports during 2023? Using reputable, December 2022 forecasts for wheat harvests during the 2022/23 season, this cBrief presents evidence on the extent of Russia's leverage and incentives.

The Russian government has the **means** to weaponize wheat exports:

- For more than a decade Russia has applied export bans, export taxes and export quotas on its wheat shipments. These policies are part of Russia's broad-based agricultural trade management. Last year alone, Russia changed export policies on agricultural goods 95 times according to the Global Trade Alert database;
- Russia could refuse to renew the temporary Black Sea agreement, which is due to expire in mid-February 2023. When Russia signaled it might withdraw from the deal in early November 2022, wheat futures prices at the Chicago Board of Trade jumped 5.8 percent. Once the deal was renewed for 120 days, futures prices fell only 2 percent;
- Russia has intervened in the wheat market through the Kremlin-owned trading company UGC since 2009. To withhold grain from the world market, UGC purchases domestically grown wheat for its stockpile. Reuters reports that UGC has offered the Kremlin to buy 3 million tons of wheat by 2024. In July 2022, the Russian Ministry of Agriculture announced that it had purchased 1 million tons of wheat.

Identifying possible **motives** for weaponization isn't hard either. These include:

- Russia needs to finance the conflict in Ukraine. Estimates vary but they are all in the range of tens of billions of US dollars. Taxes collected on the exports of billions of dollars of wheat help finance the invasion of Ukraine at a time when other revenues are at risk;

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- The mere threat of blocking Ukraine's exports reduces the incomes of farmers there, with knock-on effects for Kyiv's government revenues and, therefore, its capacity to finance its military campaign.

The extent to which Russian weaponization of wheat disrupts world markets and food security will depend on factors beyond Russia's control, including the size of wheat harvests around the world. The fact that wheat prices did not spiral out of control in the past year may be more down to good luck than good policy. IFPRI analysts point out that Argentina and Brazil were able to expand their wheat exports by 6.6 million tons during the first half of 2022. Luck may be running out according to the well regarded forecasts by the U.S. Department of Agriculture (2022*a*,*b*). In its most recent updates from December, the USDA foresees:

- stagnant global wheat production (from 779.3 million tons in 2021/2 to 780.6m tons in 2022/3);
- declining wheat production among major growers including Ukraine (by 12.5m tons), Argentina (9.7m tons), and the European Union (3.9m tons);
- rising wheat production in Russia (by 14.8m tons), Canada (by 11.1m tons), and Kazakhstan (by 2.2m tons) as well as in Brazil, China, Iran, Turkey, and the UK (by between 1m and 2m tons each).

To put these forecasts in context, recall that prior to the conflict (during 2020/21) Russia accounted for 19.2 percent of world wheat exports. Our simulations predict that, in the absence of any weaponization of wheat trade, Russia will supply 22.8 percent of world wheat exports next year, and the U.S. Department of Agriculture (2022*b*) forecasts a 20.4 percent share of Russian exports in world exports. In contrast, the nations sanctioning Russia will see their net production rise by only 0.9 percent of the world total. If Russia keeps its additional wheat production off world markets in 2023, Western wheat cannot easily replace it.

To make matters concrete, we backed out from the USDA's forecasts the implied changes in yield (productivity) for each main wheat exporter and simulated what leverage Russia has over the global wheat market in the 2022/3 season. We considered scenarios where Russia blocks different percentages of Ukrainian wheat exports and where Russia decides to cut its wheat exports by up to half. Our simulations show how much leverage the Russian Federation could have on world wheat prices and what threat Moscow poses to food security, principally in developing countries. If the Kremlin withholds a quarter of Russia's wheat exports, for example, it takes 10.8 million tons of wheat off the world market. Preventing all Ukrainian wheat shipments in the Black Sea, in contrast, only leads to small increases in Russian exports while larger shipments from other suppliers result in little change in total wheat supplies to the world market. Russia's diplomatic niceties on Black Sea transportation should therefore not be mistaken for good intentions in the wheat market overall.

We study potential export-tax regimes to measure the Kremlin's incentives to manipulate world wheat markets. For instance, a Russian export tax regime that cuts one-quarter of Russia's wheat exports generates for the Kremlin tax revenues equivalent to almost a third of the Russian wheat industry's value added. Naturally, the economy-wide cost of the resulting market distortions are large for Russia, and amount to more than one-third of wheat value added. But in a war economy this loss may matter little in comparison to the Kremlin's prospective use of export tax revenues.

Details of the simulation can be found in the main text that follows this Executive Summary. Here are key findings:

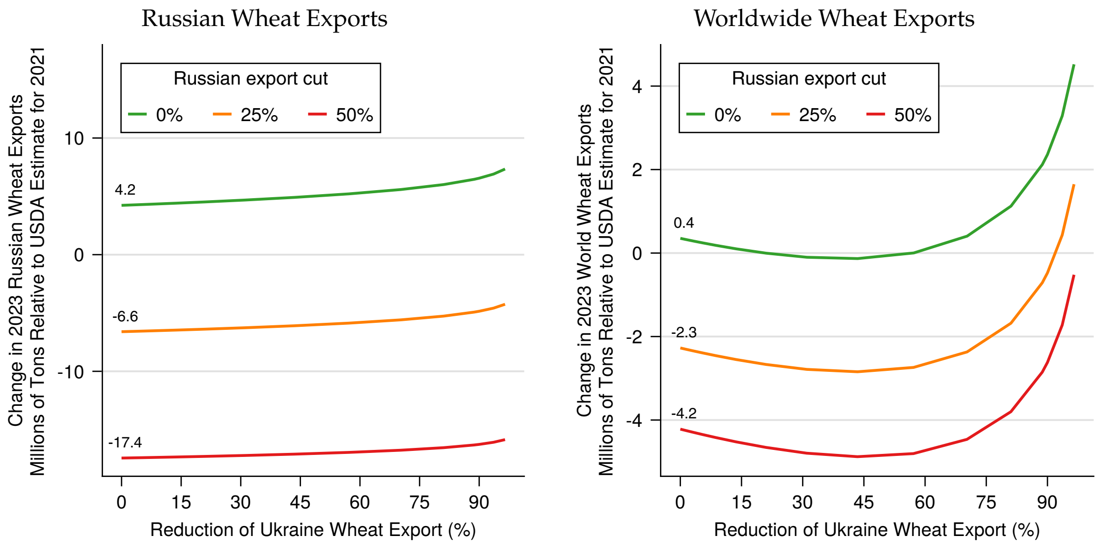
- Given wheat production forecasts, no matter how much Ukrainian wheat Russia allows to pass through the Black Sea, 2.5 million tons more wheat will be on world markets than before the conflict began. This limits the resulting wheat price hikes during 2023. Even a near-complete Black Sea transport ban on Ukrainian wheat would raise the median importer's wheat price by 4.2 percent. But sourcing patterns are such that wheat prices in the Philippines, Indonesia and Tunisia, for instance, would rise by more than 27 percent.
- If Russia putatively raises export taxes high enough to cut its wheat exports by one-quarter, and farmers across the two hemispheres respond to the intervention within the year, then world wheat imports will drop by about 2 million tons in total because competing exporters can only partially replace the lost Russian wheat exports. Under this scenario the median importing nation pays 5.2 percent more for wheat. The Kremlin's export tax collection amounts to 29.7 percent of the Russian wheat industry's value added in the absence of export restrictions.

- If Russia goes further and raises export taxes so as to cut its wheat exports in half, then total wheat imports fall by 3.4 million tons and the median importer pays 9 percent more for wheat than before the conflict. Bangladesh and Nigeria now face above-median wheat price increases of around 14 and 11 percent, while the Kremlin collects 55.6 percent of the Russian wheat industry's value added in tax revenues.

As Moscow scrambles to finance its military onslaught on Ukraine, the temptation to weaponize wheat exports grows. A larger harvest next year strengthens Russia's leverage over world wheat markets. Russia's influence on world wheat prices is greater if it hikes export taxes than if it refuses to extend the Black Sea deal. Several developing countries with large populations are at risk should Moscow weaponize exports—and contingent financing to help could be lined up now. Russian wheat producers will also be victims of weaponization, diminishing their incentive to plant in future seasons.

Foreign governments and international organizations should monitor not only Russian export tax changes but also Moscow's state purchases of wheat from Russian farmers. Conceivably, Russia could stockpile plenty of wheat and then engage in "wheat diplomacy" with countries that are desperate to feed their populations. The Black Sea deal is important but it isn't the only game in town.

Figure 1: Russian and Worldwide Wheat Exports under Alternative Policy Scenarios



Notes: Changes in gross wheat exports predicted by the GPL Model (cModel) under USDA forecasts for wheat production and alternative policy scenarios. The origin (at zero) with no Ukrainian export restrictions on the (green) curve with zero Russian export cuts shows the effect of inferred productivity changes under USDA forecasts for global wheat production. The horizontal axis measures Ukrainian export reductions in percent (up to 99 percent) under escalating transport cost increases for outward wheat shipments from Ukraine. The curves show Russian (left graph) and worldwide (right graph) exports under no Russian export taxes (green), under Russian export taxes that reduce Russian exports by one-quarter (orange), and under Russian export taxes that reduce Russian exports by one-half (red). Volumes are measured as farm-gate wheat revenues under the productivity change less the change in factor prices in the source country.

Policy Simulations

The Russian Federation was the world's largest single wheat exporter, with 38.7 million tons of net exports and a world-market share of 19.2 percent during the pre-invasion growing season 2020-21 (U.S. Department of Agriculture, 2022*b*). By comparison, Ukraine's entire annual harvest of wheat is only 25.4 million tons in the 2020-21 growing season, far less than Russia's net exports, and is dwarfed by Russia's production of 85.3 million tons. The Black Sea grain export agreement benefits Ukraine by securing safe transport of its agricultural products and garnered much public attention when the UN and Turkey brokered the 120-day extension before the agreement's expiration on November 19, 2022.

We argue in this cBrief that Russia's current acquiescence to the Black Sea deal should not blind us to the reality that Moscow can manipulate the world market for wheat by weaponizing its own exports. After more than a decade of experimenting with export taxes and, since 2020, quotas, Moscow has every reason to stick to the proven means of maximizing its export proceeds in the wheat market—especially since oil and gas revenues are drying up and now subject to price caps and import bans. By 2019, after a decade of interventions and the formation of the United Grain Company (UGC) as a state-owned wheat trader for Russia, the Kremlin has transformed wheat and grain mill products into its fifth largest export industry after mining and quarrying, nuclear fuels, basic metal products, and oil and gas. The importance of wheat in Russia's export revenues is growing with the curbs on its other export goods. Our simulations reveal that Russia can have a considerable impact on world wheat prices and much to gain from heavy-handed export-market interventions.

To assess Russia's potential leverage over world wheat markets, we proceed in two main steps. We first use the most up-to-date predictions by the U.S. Department of Agriculture's Economic Research Service (U.S. Department of Agriculture, 2022*a*,*b*) for wheat production changes between the 2020-21 and 2022-23 marketing years.[1] For most countries, the U.S. Department of Agriculture (2022*a*) forecasts a production

[1]USDA crop production estimates for Russia exclude estimated output from Crimea, all Ukraine oblasts currently under conflict, and any stolen grain from the conflict zones.

expansion, but for Ukraine a drop of 19.4 percent under Russia's invasion and for Argentina a contraction of 29.1 percent on account of a drought (for details see Table 1 in the appendix). In our simulation model (cModel; Chen et al., 2023) we attribute the USDA forecasts of wheat production to agricultural productivity changes—including natural causes such as weather shocks and farming choices that alter the wheat harvest without affecting other industries directly.

To validate our inferred agricultural productivity changes and their consistency with the USDA forecasts, we compare the predicted changes in wheat exports from the cModel to the USDA forecasts for exports and find the export estimates to be closely aligned, especially for key countries such as the Russian Federation (for details see the appendix). Our simulations predict that Russia will supply 22.8 percent of world wheat exports by 2023 in the absence of further policy interventions. (The U.S. Department of Agriculture (2022*b*) forecasts a 20.4 percent share of Russian exports in world exports by 2023 but this particular forecast by the USDA may anticipate certain policy interventions.) Other wheat exporters, not just the Russian Federation, fill the shortfall of Ukrainian exports in addition. Based on the USDA production forecast, the cModel simulation predicts that Ukrainian exports drop by 10.8 percent, from 16.85 million tons to 15.04 million tons, between 2021 and 2023 given Ukraine's harvest shortfall under the Russian invasion.

In a second step, we then study policy scenarios and their consequences through the marketing year 2022-23, taking account of the USDA forecasts of production changes. One policy scenario is a more and more restrictive Black Sea shipment ban. The resulting export cuts are depicted along the horizontal axis in Figures 1, 2 and 4 and show reductions in Ukrainian wheat exports up to 99 percent. The other policy scenario is a stepwise Russian export taxation regime depicted in three curves—for no Russian export taxes (and no cut to exports) and for Russian export taxes resulting in one-quarter and in one-half cuts of Russian wheat exports.[2] For each policy scenario, we add product-market frictions to the cModel that effectively limit short-term adjustment: production as well as household and government consumption functions have a low elasticity of substitution of one-tenth, and we reduce the trade elasticities to one-quarter of their long-term levels to reflect an impeded extensive margin of switching between suppliers (following Dekle, Eaton and Kortum, 2008). We keep local factor markets fully flexible, however, so that wheat production can smoothly respond in the cModel, reflecting the ease of crop rotation and the buffering role of wheat inventory in the real world.

Figure 1 shows in the left panel how the volume of Russian exports responds to productivity as well as policy changes. The right panel depicts the response of global wheat exports. The origin of the green curve shows the cModel predicted export volume increase consistent with wheat productivity change under the USDA production forecasts for 2022-23. Russian exports increase by 4.2 million tons under the USDA production forecasts. Worldwide exports, however, only increase by 0.4 million tons because important net wheat exporters, especially Ukraine and Argentina, reduce their gross exports under the USDA forecasts. Ukrainian exports drop by 10.8 percent, or 1.8 million tons, under the cModel simulation of the USDA forecast (a production drop of 19.4 percent in Ukraine).

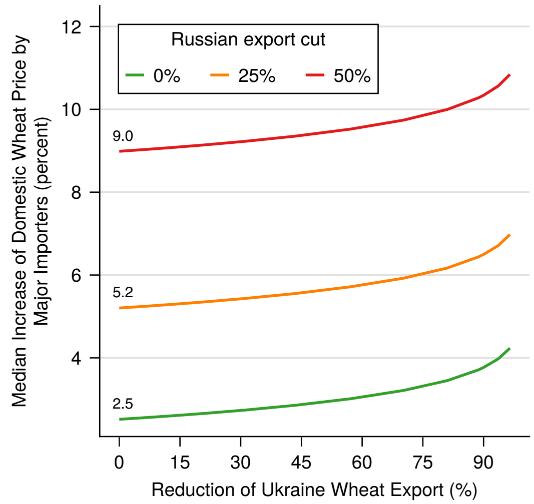
Under an export tax regime that cuts 25 percent of Russian exports, Russia effectively takes 10.8 million tons of wheat (4.2+6.6m tons) off the world market (orange curve). A total of 21.6 million tons of Russian wheat exports is removed under a tax regime that results in a 50-percent export cut (red curve). The Russian export tax scenarios more than reverse the productivity-induced export expansion that would occur under free markets (an expansion of 4.2 million tons beyond the 39.1 million tons of Russian wheat exports in the pre-invasion growing season 2020-21). The slight upward slope of each of the three Russian tax scenario curves shows that gradually banning Ukrainian wheat shipments benefits Russian exports only little, even for a 99-percent reduction in Ukrainian shipments. The slight benefit is dwarfed by Russia's self-imposed export cuts.

The reason why Russia would not benefit commercially from blocking all Ukrainian shipments through the Black Sea is that wheat growers elsewhere strongly respond to the attendant upward pressure on world wheat prices once the reduction in Ukrainian shipments goes beyond 45 percent.[3] Figure 1 shows in the right panel that preventing about 45 percent of Ukrainian wheat exports results in a net drop of world exports by only 0.5 million tons (a drop of the green curve to -0.1 million tons, even though Ukraine fails

[2]Since 2020, Russia has imposed an export quota on wheat shipments between 7 and 17.5 million tons every winter and subsequently replaced the quota with an adjustable export tax regime to target a set wheat export price for the remainder of the year.

[3]In the simulations, we take the remaining growing season in 2023 as long enough so that global wheat production across both hemispheres can respond by December 2023 to a failure of the Black Sea agreement in February.

Figure 2: Median Wheat Price for Importers under Alternative Policy Scenarios



Notes: Changes in the user price of wheat for the median importer predicted by the GPL Model (cModel) under USDA forecasts for wheat production and alternative policy scenarios. Turkey is the importer with the median price change according to the cModel. The origin for no Ukrainian export restrictions on the (green) curve with zero Russian export cuts shows the effect of inferred productivity changes under USDA forecasts for global wheat production. The horizontal axis measures Ukrainian export reductions in percent under accelerating transport cost increases for outward wheat shipments from Ukraine (up to 99 percent). The curves show the median importer price change under no Russian export taxes (green), under Russian export taxes that reduce Russian exports by one-quarter (orange), and under Russian export taxes that reduce Russian exports by one-half (red). User prices in import countries are measured as the source countries' farm-gate wheat revenues under the productivity change less the change in factor prices in the source country plus the change in transport costs and export taxes.

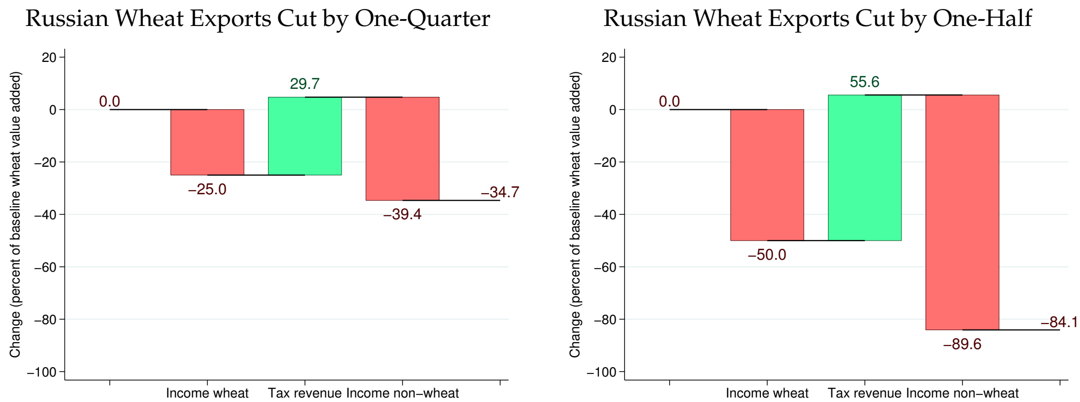
to deliver 6.8 million tons (45 percent of Ukraine's post-invasion exports of 15.04 million tons). Competing export countries essentially replace the foregone Ukrainian supplies to the world market. A reduction of Ukrainian shipments by 70 percent induces such strong a response from other wheat exporters that total supplies to the world market are about the same as in the absence of interference in the Black Sea. A further disruption of Ukrainian shipments by more than 70 percent triggers more than proportional export expansions from competing wheat suppliers because of a strong wheat price increase. In short, a complete ban of Ukrainian exports through the Black Sea would invite Russia's competitors in the global wheat market to expand supplies, and a partial ban of say half of Ukraine's exports does not help Russian exports much.

Figure 2 reports the wheat price change for the median importer in our cModel simulation of USDA wheat production forecasts and alternative policy scenarios. For the case of no weaponization of Russian exports (green curve), the wheat price for the median importer increases by 2.5 percent.[4] A further reduction in Ukrainian shipments results in a wheat price increase for the median importer by 4.2 percent (at the right-most tip of the green curve), one percent less of a price increase than resulting from a Russian export cut of 25 percent. We report the median price change because the mean price move is driven by extreme outcomes.

For China, an important net importer of wheat but also the world's largest wheat grower, USDA forecasts of domestic production increases lead to a price drop of -2.5 percent in our cModel simulation, and that drop is mostly unaffected by any Russian or Ukrainian export reductions. In contrast, at the upper end a complete Ukrainian export ban (a 99-percent export reduction) raises wheat prices in the Philippines, Indonesia and Tunisia by more than 27 percent. A partial Ukrainian export reduction is expectedly less serious: a Ukrainian export reduction of say 50 percent results in about 9 percent higher prices in the most adversely affected countries, the Philippines and Bangladesh in this case. Direct Russian interventions in the world wheat market are more consequential. A Russian export cut of 50 percent results in the extreme

[4] In the simulations, Turkey is the median importer and, as a destination of Ukrainian wheat, suffers a 2.5-percent price increase because the USDA forecasts a large reduction in the Ukrainian wheat harvest.

Figure 3: Costs and Benefits of a Wheat Export Tax Regime



Notes: Changes relative to wheat value added predicted by the GPL Model (cModel) under USDA forecasts for wheat production and reported for Russian export taxes that reduce Russian exports by one-quarter (left graph) and by one-half (right graph). In the Ricardian Eaton and Kortum (2002) model with constant elasticities, foregone wheat value added and the equivalent foregone income from wheat are proportional to foregone export revenues. The foregone welfare and equivalent foregone per-capita income for the remaining Russian economy outside the wheat industry accounts for the distortions from the tax and economy-wide lower factor incomes.

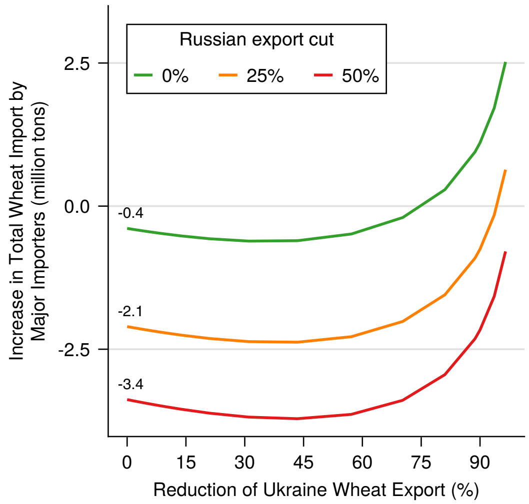
in wheat price increases of 13.8, 10.8 and 9.0 percent in Bangladesh, Nigeria and Turkey, respectively.

In the short term, when substitution elasticities and trade elasticities are low, reducing exports through export taxes raises a country's revenues per ton of wheat swiftly—just like a private-sector wheat monopoly can restrict its sales to raise price. As shown in Figure 3, our cModel simulations suggest that an export tax regime that cuts one-quarter of Russia's exports generates substantive tax revenues for the Kremlin (see green bar in left graph) and even larger tax revenues under a cut of Russian exports by one-half (see green bar in right graph). Wheat exports contract and wheat value added drops proportionally under the export tax regimes considered here, so the income of Russian farm owners and workers in the wheat industry diminishes with the drop in wheat value added by 25 and 50 percent (first red bar in each graph). But the Kremlin collects 29.7 of the baseline wheat values added (after the USDA forecast of Russia's production expansion) under a 25-percent export cut through export tax revenues and 55.6 percent of baseline value added under a 50-percent export cut (second and green bar in each graph). Those tax revenues help fund Russia's invasion of Ukraine. Restricting exports of wheat, a major crop in Russia, is costly for the Russian economy as a whole: a drop in economy-wide per-capita incomes outside of the wheat industry results in an overall Russian per-capita income loss to the tune of 35 (left) and 84 percent (right graph) of the size of the wheat industry's value added (second red bar in each graph). In a war economy, however, that economic distortion may matter little to the Kremlin given the lure of substantive export tax revenues.

Russia's strategic intervention in the wheat market has global consequences. Figure 4 restricts attention to the countries that the USDA considers major wheat importers (for the list of countries see footnote 6.) The figure shows how the volume of imports responds to productivity as well as policy changes. The origin of the green curve shows the cModel predicted import volume drop by 0.4 percent, consistent with wheat productivity changes under the USDA production forecasts for 2022-23. Especially the shortfall of shipments from Ukraine under the invasion and Argentina under its drought hamper wheat purchases for major importers. As mentioned above, our cModel predicts a drop of wheat shipments out of Ukraine by 1.8 million tons (10.8 percent) in the absence of any transport restriction in Ukraine and in the absence of Russian export taxes, and a decline of Argentine exports by 1.7 million tons (14.8 percent). The Russian export tax scenarios further aggravate the productivity-induced import contraction and cause 1.7 million tons of additionally "missing" wheat imports under a 25-percent export cut and 3.0 million tons of additionally "missing" imports under a 50-percent cut of Russian wheat exports.

The upward slope of each of the three curves in Figure 4 shows that reducing Ukrainian wheat shipments more and more, in addition to Ukraine's production decline, induces imports from other suppliers than Ukraine. That gradual inducement of replacement exports does not fully compensate the Ukrainian

Figure 4: Major Wheat Buyers’ Total Imports under Alternative Policy Scenarios



Notes: Sample of countries restricted to major wheat importers according to the U.S. Department of Agriculture (2022*b*, for the country list see footnote 6). Changes in wheat imports predicted by the GPL Model (cModel) under USDA forecasts for wheat production and alternative policy scenarios. The origin for no Ukrainian export restrictions on the (green) curve with zero Russian export cuts shows the effect of inferred productivity changes under USDA forecasts for global wheat production. The horizontal axis measures Ukrainian export reductions in percent (up to 99 percent) under accelerating transport cost increases for outward wheat shipments from Ukraine. The curves show worldwide imports under no Russian export taxes (green), under Russian export taxes that reduce Russian exports by one-quarter (orange), and under Russian export taxes that reduce Russian exports by one-half (red). Volumes are measured as user wheat expenditures under the productivity change in the source countries less the change in factor prices in the source countries plus Ukrainian transport cost and Russian export tax increases.

shortfalls initially but, at around a 70-percent export curb on Ukraine, starts to make up entirely for the Ukrainian shortfall because wheat prices in major import destinations, with the exception of China, rise more than proportionally. In contrast, Russian export restrictions by 25 and 50 percent reduce worldwide imports much more. While a 50-percent drop in imports from Ukraine (around the minimum of the green curve) cuts somewhat into world wheat imports, a 50-percent export cut of Russian wheat cuts sharply into wheat importers’s supplies (the shift of the green to the red curve).

Households in countries with lower per-capita income consume considerably larger shares of cereals in their daily energy intake and relatively small proportions of protein, compared to those in higher-income countries. Consumers of wheat in lower per-capita income nations are therefore especially vulnerable. Moreover, there are downside risks in the USDA forecasts and wheat production shortfalls may worsen further.

From a decade of experience with wheat-market interventions, Russia has the tools to optimize its revenues and generate foreign currency receipts that help fund the Kremlin’s expenses, including those for Russia’s invasion of Ukraine.[5] Playing soft on the Ukrainian wheat shipments through the Black Sea is a strategic choice while the Kremlin’s own wheat export policy warrants more scrutiny.

[5]More than a decade ago, the Kremlin first placed a ban on wheat exports in August 2010 and kept it through June 2011 to secure domestic supplies at low local prices under a bad harvest. There is a broadly held consensus that the Kremlin’s full export ban of 2010 did not meet its stated domestic policy objectives. But the Kremlin learnt about world-market responses. As a precursor to outright export quotas, in 2014-15 Russia imposed (arguably WTO-rule consistent) phytosanitary controls and reported slow rail service to explain lacking wheat exports and, from February through May 2015, followed the implicit quotas with an export tax. For even longer, since 2009, the Kremlin has been coordinating wheat trade through its United Grain Company (UGC, also known as the OZK Group by its Russian acronym). UGC which is majority owned by the Kremlin’s Federal Property Management Agency and is among the top-5 exporters of Russian grain by its own estimates. UGC’s publicly declared objectives are the attainment of global market control and the reduction of foreign traders’ market shares through commodity interventions. Since June 2021, the Kremlin has a permanent export tax on wheat in place. Prior export taxes were temporary. Despite record wheat production in 2020, Russia imposed an export quota of 17.5 million tonnes in early 2021 and, when the quota expired, followed with an export tax. In 2020, the Kremlin had first imposed a quota early in the year, and did so in 2022 again. Beyond the temporary quotas, the export tax is permanent and varies with the wheat price. The sales-price dependent design of the Russian export tax at present is meant to guarantee a revenue of close to 15,000 roubles (roughly $280) per ton of wheat from either sales or tax revenues.

Box: Key features of the cModel

Junyuan Chen, Carlos Góes, Marc-Andreas Muendler and Fabian Trottner, UC San Diego (2023)

Our computational model (cModel) is based on the Ricardian trade framework by Eaton and Kortum (2002), with competitive global markets for goods and services and with competitive local factor markets for labour and capital. Goods and services enter production as intermediate goods in addition to their final uses by households and government. In each industry and country, producers combine local labour and capital with globally sourced intermediate inputs and offer a set of varieties. An active government in each country collects revenues from taxes and tariffs, while government expenditure is spent on subsidies as well as goods and services procurement. Producers, households and governments globally source varieties within industries from the least costly producer. The simulation algorithm, implemented in Julia, calls equilibrium convergence for mutually consistent producer, household, and government decisions and budgets. Each country's observed net exports or imports (a trade surplus or deficit) are exogenous.

From the ITPD-E data Release 1 (May 2020) by Borchert et al. (2020), we obtain production and trade flows for 170 supply industries in the benchmark years 2014-2016, including services trade. To account for the input-output relationships across countries and activities, we employ the WIOD data by Timmer et al. (2015) for the year 2014, extracting shares of supply industries by source country in use industries by destination (under Cobb-Douglas production) as well as expenditure shares of supply industries in (Cobb-Douglas) household and government consumption. Using shares of supply industries within use industries preserves positive value added by use industry but can result in negative inventory changes for data consistency. We apply the Wolsky (1984) disaggregation to infer a consistent input-output structure for the 170 ITPD-E industries that map into 38 matching aggregates of the 56 sectoral activities in WIOD. The baseline cModel has 43 individual countries plus an aggregate of the rest of the world for mutual consistency between ITPD-E and WIOD datasets. The combined data allow us to infer all shares in production, consumption, and procurement. To calibrate elasticities, including industry-specific trade elasticities that measure the responsiveness of trade flows to prices, we use WITS tariff data for goods and an average tariff to approximate services trade barriers in gravity equations (Head and Mayer, 2014). Modules to the baseline cModel allow for extensions: the rest of the world can be broken down into individual countries as needed; Cobb-Douglas production as well as Cobb-Douglas household consumption and government procurement functions can be replaced with constant-elasticity of substitution functions under a low elasticity of substitution such as one-tenth; factors can be made immobile and their industry-specific factor prices solved instead of economy-wide factor prices; and to allow for an impeded extensive margin of switching suppliers the trade elasticity can be adjusted to a short-term level following Dekle, Eaton and Kortum (2008).

Detailed cModel documentation is available from the authors Chen et al. (2023). We explain our extensions of the baseline model in the appendix to this cBrief.

Appendix: Calibration to USDA Forecasts and Simulation Procedure

To implement a suitable version of the baseline cModel for wheat production and export simulations, we require a larger number of countries to be treated separately. We break out eight countries from the baseline rest of the world so that the adjusted cModel has 51 countries and a smaller rest of the world. The eight additional countries are Argentina, Bangladesh, Egypt, Morocco, Nigeria, the Philippines, Tunisia, and Ukraine. Of these, the USDA considers Bangladesh, Egypt, Morocco, Nigeria, the Philippines, and Tunisia major wheat importers and Argentina and Ukraine major wheat exporters.[6] Argentina is a major wheat source for Brazil and other countries, whose imports would erroneously be confounded with Ukraine shipments if Argentina and Ukraine were not separated out from the rest of the world. Conversely, Egypt, Bangladesh, Nigeria, the Philippines, Morocco and Tunisia receive major import shipments from Russia or Ukraine, so they need to be taken out of the rest of the world to properly attribute bilateral Russian and Ukrainian trade flows. For wheat importers in the baseline model that do import much of their wheat from other sources than Russia or Ukraine, such as Japan and South Korea, splitting Ukraine and Argentina from the rest of the world prevents confounding price changes and wheat import substitution towards other countries.

For the eight added countries (separated out from the baseline rest of the world), we only require two types of data to conduct the cModel simulations: import shares to compute production and trade, and country size (value added) to compute factor incomes. We obtain average import shares from ITPD-E Release 2 (July 2022) by Borchert et al. (2022), taking averages over 2013-2019 to reflect recent wheat trade. We assume that the eight added countries share the production and consumption parameters with all other rest-of-world countries outside of the wheat industry. In the case of Ukraine, the USDA reports that Russian wheat production is 3.4 times that of Ukraine in 2021 so we adjust the size of Ukrainian wheat production to match the ratio of 3.4. For country size (value added), we use GDP from the World Development Indicators.

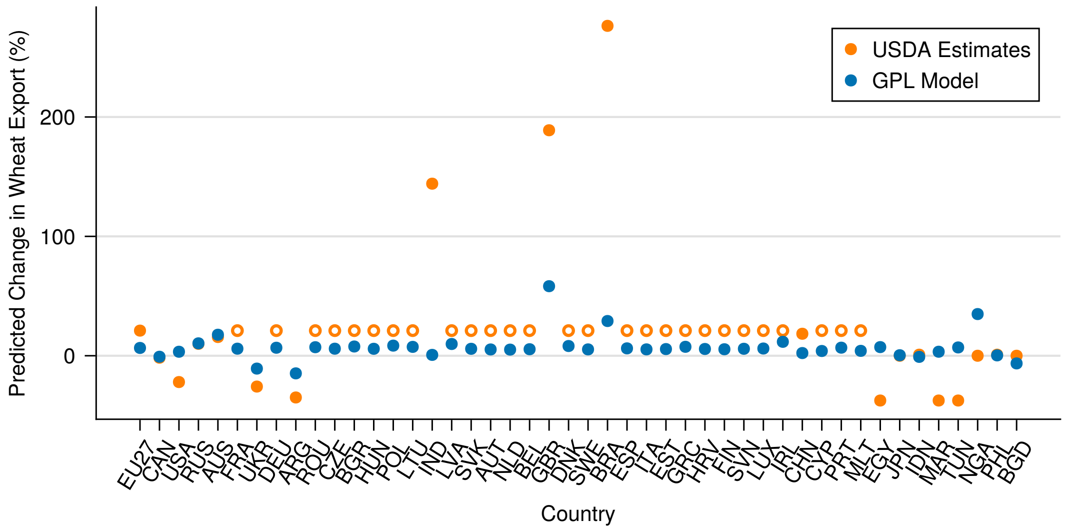
We simulate the global wheat market changes in two main stages. First, we implement the December 2022 USDA forecasts of expected wheat production (U.S. Department of Agriculture, 2022*a*,*b*) and use the baseline cModel, extended to 52 countries (51 countries and a reduced rest of the world), to infer the changes to wheat growing productivity that are consistent with the USDA forecasts. The underlying productivity changes that we infer on this first simulation stage include natural causes, such as weather shocks, and farming choices that alter the wheat harvest without affecting other crops or the factor allocation.

For this cModel based inference of USDA implied productivity changes, we consider a flexible economy with Cobb-Douglas production and consumption functions and long-term trade elasticities at their full level. The computation of productivity changes in the cModel is set to match the USDA forecast of production volumes, which we measure as farm-gate wheat revenues from the productivity change less the change in factor prices in the source country. Table 1, in the final column, reports the cModel inferred productivity changes under the USDA production forecasts for the main USDA countries. As a byproduct of matching production volumes, the cModel predicts export volume changes.

Before we proceed to the second stage of simulation, we contrast our cModel predicted export changes with USDA export forecasts to validate our first stage. To compute export volumes, we evaluate all bilateral flows for each source country in the cModel and compute the quantity change as the change in productivity less the change in factor prices and then aggregate across destinations. Figure 5 shows the export comparison. For the most relevant countries in our wheat market simulations the cModel export predictions are similar to the USDA forecast. For Canada, the Russian Federation and Australia, among the world's largest wheat exporters, our export predictions and the USDA forecast essentially coincide (see Figure 5). For Ukraine, the EU-27 (the world's largest wheat exporter for which the figure also shows the individual member countries) and China (the world's largest wheat producer but also a large net wheat importer) our predictions are similar to the USDA forecast but more moderate. For the important wheat exporter Argentina, which is undergoing a severe draught, the cModel's prediction of the export decline (–15 percent) is also more moderate than the USDA forecast (–35 percent). For the wheat exporters Brazil

[6]The U.S. Department of Agriculture (2022*a*,*b*) lists the following countries as major importers: Algeria, Bangladesh, Brazil, China, Egypt, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kuwait, Lebanon, Libya, Malaysia, Mexico, Morocco, Nigeria, Oman, Philippines, Saudi Arabia, South Korea, Thailand, Tunisia, Turkey, United Arab Emirates, Vietnam and Yemen. Of these countries, the extended cModel uses the following ones individually: Bangladesh, Brazil, China, Egypt, Indonesia, Japan, Korea, Mexico, Morocco, Nigeria, Philippines, Tunisia and Turkey.

Figure 5: Predicted Export Changes under USDA Production Forecast



Notes: Changes in gross wheat exports by country between 2020/21 and 2022/23, predicted by the GPL Model (cModel) under USDA forecasts for wheat production 2022/23. The USDA forecasts of wheat production are attributed solely to wheat productivity change under an extension of the baseline cModel by eight additional countries from within the baseline rest of the world.

and India, the USDA forecasts strong export increases (Brazil 376 percent and India 244 percent) whereas our cModel predicts smaller, considerably more modest export expansions (29 percent and 0.7 percent); also for the United Kingdom (the economy with the world's highest productivity in terms of wheat yield per area according to the USDA), the cModel predicted export increase is more conservative (58 percent instead of 289 percent). For the United States (a net wheat exporter), the USDA forecast (–2 percent) and cModel prediction (3 percent) differ in sign, with the cModel predicting a gross export increase despite the production decline. The reason is that the cModel keeps the country-wide trade balance constant, requiring the United States to maintain agricultural exports.

On the second stage of our global wheat market simulation, we take the implied changes to wheat productivities from the USDA forecasts as given, determine the factor allocation in the new equilibrium, and consider two types of policy interventions that alter the equilibrium implied by the USDA forecasts. On the one hand side we simulate a gradual restriction of Ukrainian wheat exports through a continually more binding Black Sea transport ban, which we capture in the cModel through gradually (and in effect more than proportionally) increasing transport cost for outward wheat shipments from Ukraine that generate no government revenue. The variation in the Ukrainian outward transport cost factor depresses Ukrainian exports gradually from zero up to 99 percent (a 100-percent shutdown of wheat trade is not possible in a Ricardian model because marginal returns tend to infinity). On the other hand side we simulate two Russian interventions in the wheat export market—a Russian export tax that reduces Russian wheat exports by 25 percent and another Russian export tax that reduces Russian wheat exports by 50 percent. These export interventions cause foregone income to the production factors in the Russian wheat industry (workers and farm capital owners) as well as distortions to the Russian economy as a whole outside the wheat industry. However, the export taxes also yield tax revenues to the Russian government.

For both types of policy interventions we simulate short-term changes in market outcomes. We therefore adopt CES production as well as CES household consumption and government procurement functions with a low elasticity of substitution of one-tenth between inputs, instead of Cobb-Douglas functions with a unitary elasticity. Similarly, for the short run we impede the extensive margin of switching suppliers by cutting trade elasticities to a quarter of their long-term level following Dekle, Eaton and Kortum (2008). To arrive at wheat trade volumes in quantity terms (millions of metric tons), we scale the expenditures paid by users with the productivity changes that reflect the competitive price changes, we eliminate changes in trade cost (for Ukraine) and export tax (for Russia) from the user prices, and we divide by increases in the source country's factor prices. However, when we compute the price changes that users in importing countries face (such as in Figure 2), we include in the prices changes the trade costs and export taxes.

Table 1: Production, Exports, Net Exports and Implied Productivity Change

	2020-21 (million t)			2023/2021 (percent change)	
Country	Production	Exports	Net Exports	Production	Productivity[a]
Russian Federation	85.4	39.1	38.7	6.6%	4.6%
Canada	35.4	26.4	25.9	-4.6%	-3.3%
EU-27	126.7	29.7	24.4	6.0%	5.2%
United States	49.8	27.1	24.3	-9.7%	-7.0%
Ukraine	25.4	16.9	16.7	-19.4%	-12.9%
Argentina	17.6	11.5	11.5	-29.1%	-23.0%
Kazakhstan	14.3	8.2	-1.8%		
India	107.9	2.6	2.5	-4.5%	-4.6%
China	134.3	0.8	-9.9	2.8%	2.5%
United Kingdom	9.7	0.5	-2.8	59.4%	49.5%
Japan	1.0	0.3	-5.2	5.0%	1.0%
Brazil	6.3	0.9	-5.5	52.0%	19.9%
Nigeria	0.1	0.6	-6.0	83.3%	32.0%
Bangladesh	1.2	0.0	-7.2	-6.8%	-5.2%
Iran	15.0			-12.0%	
Iraq	4.6			-35.3%	
Algeria	3.1			19.0%	
Egypt	8.9			10.1%	6.5%
Morocco	2.6			5.5%	3.5%
Mexico	3.0			20.2%	8.5%
South Korea	0.0			200.4%	68.9%
Turkey	18.3			-5.5%	-4.1%
World	774.6	203.3	8.6[b]	0.7	

[a]cModel computation.
[b]The USDA figures allow for storage (and possibly loss during transit).

Sources: U.S. Department of Agriculture (2022*a*,*b*); GPL model (cModel) for inference of productivity change.
Notes: Production, exports and net exports 2020-21 as reported by USDA and production change 2023/2021 as forecast by USDA (all but final column). Implied productivity change (final column) inferred from cModel computation. Countries sorted by 2020-21 net exports. Algeria, Kazakhstan, Iran and Irag are part of the rest of the world in the cModel with an average productivity decline of –1.2%. For Iran and Irag as well as for Algeria, Egypt and Morocco, the public USDA reports do not permit a precise assignment of net exports; for Mexico, South Korea, and Turkey no assignment is possible.

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