Journal of Agricultural and Resource Economics 49(1):162–184 ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.337556

Implications of the Russian Invasion on the Logistical Competition for Corn Shipments from the United States and Ukraine

William W. Wilson, Prithviraj Lakkakula, and David W. Bullock

The Russian invasion of Ukraine resulted in disruptions in grain flows from that region. As a result of the invasion, Ukraine has evolved from a country with some of the lowest logistical costs in the world to having the highest logistical cost. This paper's purpose is to analyze the effects of the Russian invasion on the logistical functions and the costs for corn exports from the Ukraine and its competitors using an optimized Monte Carlo simulation model. Most important are the effects of the radical increase in shipping costs from the Ukraine, reduced port capacity and export supplies.

Key words: Monte Carlo simulation, optimization, sensitivity analysis, trade flow analysis

Introduction

During the 2000s, Ukraine emerged as a large and fast-growing corn exporter into markets that the United States had traditionally dominated. The United States was the dominant exporter of corn during the 1970s and 1980s, but its market share has declined since then. Ukrainian corn exports increased from 0.49 million metric tons (mmt) in 2002 to an all-time high of 32 mmt in 2019. In recent years, China has become increasingly dominant in corn imports, first, from Ukraine and, more recently (commencing Fall 2022), from Brazil (Mano, 2023).

The Russian invasion challenged the Ukrainian logistical system, hampering its ability to export grain and oilseeds. The invasion has had numerous effects, including a shortage of storage space for the 2022 crop (Yale School of Public Health, 2022); landmines causing problems for field work (Kullab, 2023; Sorvino, 2023; Wright et al., 2023); nuclear-contaminated soils, potentially reducing yield for many years (Ivanova and Olearchyk, 2023; Nickel, 2023); trade controversy with Romania, Poland, and Hungary for depressing local cash prices (McGrath and Erling, 2023) and, by April 2023, seeking to restrict grain flows from Ukraine to Poland but allowing grain to transit through Poland (Reuters Staff, 2023); Russia's looting of Ukrainian export grain (Ivanova, 2023); cash-flow problems, which constrained seeding for the 2023 crop; and the need to develop alternative logistical channels. However, one of the most important changes that influenced export competitiveness was the war's effect on export logistics.

Briefly, changes in logistical functions involve increased costs—including elevation; interior logistics; export handling; rail, truck, and barge shipping to alternative routes; port-area capacity constraints; increased Black Sea ocean-shipping costs relative to alternative routes; and reduced exportable supplies for 2023 forward. Finally, the "Grain Corridor" was conceived in May 2022

William W. Wilson is the University Distinguished Professor and CHS Chair in Trading and Risk, Prithviraj Lakkakula was a research assistant professor, and David W. Bullock is a research associate professor in the Department of Agribusiness and Applied Economics at North Dakota State University.
This research was supported by Cooperative Agreement Number 20-TMTSD-ND-0004 with the US Department of Agriculture, Agricultural Marketing Service

Review coordinated by Timothy Park.

(as originally described in European Commission, 2022) and was negotiated and implemented to facilitate shipping through selected ports around Odesa (used throughout to be inclusive of Odesa, Chornomorsk, and Yuzhny/Pivdennyi), primarily to poorer countries, commencing on July 14, 2022. Grain Corridor negotiations are ongoing, in part, due to Russia seeking concessions against varying sanctions (Hall, 2023). The United Nations indicated that the corridor has significant challenges as it approaches additional negotiations; in late April 2023 (Worledge, 2023), Russia threatened to end the Grain Corridor Agreement unless other concessions were provided (e.g., as discussed in Malsin and Cullison, 2023). Finally, in late July 2023, Russia withdrew from the Grain Corridor Agreement and subsequently began bombing Odesa and the Danube ports. In addition to the changes affecting logistical competition, there were near-concurrent changes in China's phytosanitary restrictions on corn imports from Brazil as well as a relaxation of the European Union's (EU) import tariffs.

Major factors that influence competitiveness for the world's corn market include, but are not limited to, supply, inland logistics including barge costs, elements of rail costs, and ocean shipping (*Hellenic Shipping News*, 2022), all of which are volatile, in addition to trade interventions. This paper analyzes the effects of the Russian invasion on the logistics of corn exports and trade from Ukraine and its competitors by using an optimized Monte Carlo simulation model. Our focus is on least-cost trade flows from the major export ports to the major importing countries and regions and, in particular, how changes in logistical costs and selected trade policies may impact short-term, inter-country competition and commodity flows.

Background and Previous Studies

Substantial institutional, trade, and marketing practices affect international competition for corn.

Logistics for the International Corn Market and Competition

Shippers arrange, manage, and incur costs and risks for all logistical functions, including interior and export handling, interior rail and barge shipping and risks, and ocean shipping. Ultimately, the costs for these functions are partially affected by each country's competitive, institutional, and regulatory mechanisms; taken together, these factors affect the country's logistical advantage. For these reasons, shippers face challenges in analyzing the effect of logistical functions and costs and their effect on international competitiveness as well as managing policies that affect logistics.

Over the past several decades, the US grain-marketing system has undergone notable changes in logistics, including expanded export-handling capacity, the adoption of forward-shipping instruments (secondary railcar markets), shuttle rail shipping, and massive investments in the country handling and rail infrastructure, all of which lower marketing costs.[1] Recent studies have shown that these mechanisms also affect the export basis values (Bullock and Wilson, 2020; Wilson and Lakkakula, 2021). In addition, US railroads use periodic "rail unload incentives" to make exports competitive in targeted transactions; other studies have illustrated the effects of these mechanisms on exports (Kamrud, Wilson, and Bullock, 2023). The US logistics system is heavily dominated by its river system, which provides low-cost barge shipping. However, barge rates have substantial seasonality and volatility (both intrayear and interyear), and the river system needs upgrading (Informa Economics, 2018). Finally, US growers have significant on-farm storage relative to competitor countries and relative to crop size.

Changes in Ukraine's agriculture (Lyddon, 2021; Pleasant, 2021) and its grain marketing system are evolving (Salin, 2020; Sizov, 2020; Wilson, 2020). Over the past decade, Ukraine has experienced moderate increases in storage and country elevators and expansion in export capacity. Interior rail-shipping costs were extremely low by international standards, but these have not translated into low rail shipping costs to and through Europe due to differences in rail gauge. In recent years, Ukraine has partially adopted a form of shuttle shipments and has increased the use

[1] These mechanisms are described elsewhere (Wilson, Bullock, and Lakkakula, 2020).

of private rail cars. Competitive rivalry among export handlers put downward pressure on margins. Additionally, Ukraine has a historically important river system, but the Dnieper River has been underdeveloped, underutilized, and in need of upgrades (CFTS Consulting, 2014).

An important function that influences trade is ocean shipping rates, which are highly volatile (Sadden, 2021). The US Pacific Northwest (PNW) has consistently lower ocean-freight rates to the Asian markets. Rates from the US Gulf and Ukraine are normally more comparable. Changes in ocean rates have greater effects for shipments from the US Gulf and Ukraine due to relative distances. Of importance is the spread between the US PNW and the US Gulf, for which changes favor the US PNW, and changes in the spread between Ukraine and the US Gulf to China, which have been advantageous to the former.

Export-market shares were affected by ocean shipping costs and differentials in the period following mid-2020 (Ren, 2021; Thukral and Maguire, 2021) in addition to changes with the interior logistical costs. Wilson, Lakkakula, and Bullock (2022) analyzed the effects of these logistical functions on export-market shares. Changes in barge rates, secondary rail values (DCV) and rail unload incentives influence export costs and market shares. DCV increases adversely affect US market shares the most (Kamrud, Wilson, and Bullock, 2023).

Effects of the Russian Invasion on Export Logistical Costs from Ukraine

The Russian invasion has had and continues to have numerous ramifications on Ukrainian agriculture. Most important for the purpose of the model developed in this paper are the changes in logistical routes, costs, and functions. Ukraine has traditionally had some of the lowest export-shipping costs in the world (Wilson, Lakkakula, and Bullock, 2022, 2023).

The effect of the invasion was dramatic. Shipping costs rose to become among the highest in the world. UkrAgroConsult (2022) described new shipping routes and costs in addition to the extreme paucity of relevant data for analysis. There were increases for interior and port elevation; higher rail and truck shipping costs; increased ocean rates, both in general and relative to competing routes; and added costs related to the Grain Corridor, including war and commodity insurance, demurrage, delays, and inspection costs. Due to closing the Black Sea routes from Odesa, its reopening subject to the subsequent Grain Corridor mechanism, and the concurrent reduced export capacity, alternative routes were developed. While multiple routes have been proposed and explored, the dominant path was for shipments through the Danube for exports from Constanta, and shipments through the western border for exports via Poland. These routes are in addition to reduced exports through Odesa and the Grain Corridor. These alternative routes incur longer and more uncertain transit times, have higher costs, and are subject to reduced export-handling capacity. Export costs and transit times are also greater due to the Grain Corridor's operations.

To illustrate these effects, we developed details about the logistical routes and costs through discussions with Ukrainian trading firms and using publicly available data. Preinvasion, the predominant origin was Odesa. During the postinvasion period, alternative routes were included (Table 1). Most important are for shipments through Odesa, subject to the Grain Corridor provisions, in addition to shipments through Constanta and rail through the western border. As a result of the invasion, interior and export elevation costs increased. Additionally, interior rail costs increased (Interfax-Ukraine, 2022),[2] and barge shipping costs exceeded the tariffs. There were added costs, including trucks and barges as well as handling, for the alternative routes. Taken together, the preinvasion costs from farm to free-on-board (FOB) ship were \$31/metric ton (mt) and increased to \$70/mt, \$115/mt, and \$130/mt for shipments via Odesa, Constanta, and rail through the western

[2] Nibulon, a major exporting company with export operations through Mykolaiv, indicated that prewar "farm-to-ship transport costs [were] as low as \$5 a tonne." In response to the war, Nibulon "had to reinvent its logistics chain, as have all of Ukraine's grain companies. With no access to the Black Sea and much of the Dnipro off limits, the invasion pushed up transport costs to over \$150 a tonne" (Rathbone and Hall, 2023; Kullab, 2023).

Table 1. Ukraine's Export Assumptions: Pre- and Post-Invasion

	Pre-Invasion	Post-Invasion		
	Odesa	Odesa	Constanta	Rail through Western Border
Export logistics costs (US$ per metric ton)				
Interior elevation	3	5	5	5
Rail to Odesa	20	35	40	
Rail to Izmail				
Rail to border				40
Elevation			20	20
Rail				55
Barge			40	
Export elevation	8	30	10	10
Ship for export (free-on-board)	31	70	115	130
Added grain corridor costs (e.g., war insurance, inspection)		27		
Total logistical costs	31	97	115	130
Export capacity per month (million metric tons per month)	7	3	3	1.5
Average basis to growers (US$ per metric ton)	+37	−90		

Notes: Values indicate the costs for each logistics function and capacities, and basis values to growers, for shipments through each of the alternative routes. Odesa includes the broader regional ports, including Odesa, Chornomorsk, Yuzhny/Pivdennyi. The results show that total logistical costs increased substantially and export capacity decreased in the postinvasion period. Average basis to growers was derived as follows: Prewar (Q3 2019–Q4 2021) vs. postwar (Q1 to Q2 2022), but as low as −151 during Q3 2022.
Source: Authors' calculations based on interviews with major Ukrainian grain traders. Average basis was derived using data from US Department of Agriculture (2019–2021).

border, respectively. For comparison, competing US origins during the same period were around $57/mt and $47/mt through the US PNW and US Gulf, respectively.[3]

There are also capacity restrictions through these routes, which were estimated to decrease from 7 mmt/month at Odesa preinvasion to approximately 3 mmt/month, 3 mmt/month, and 1.5 mmt/month, respectively, for shipments via Odesa, Constanta, and rail through the western border. Added costs of shipping through the Grain Corridor were approximately $27/mt due to war and grain insurance, demurrage, inspection costs and increased transit time. Finally, for numerous reasons, ocean shipping costs for shipments from the Black Sea to all destinations increased relative to competing ports. As an example, the ocean rate from the Black Sea to Egypt was $12 over the US Gulf rate in February 2022, and that differential increased to $34 in November 2022 (AgriCensus, 2021).

The cumulative effect of these changes was to reduce the price paid to Ukrainian farmers. To capture this scenario, we derived the basis at the farm level in Ukraine relative to nearby CME futures by using data from 2019 to mid-2022. The results indicated that the average basis decreased from about +$37/mt preinvasion to −$90/mt in early 2022. These changes are dramatic, reflecting a price decrease of $127/mt for growers, resulting in the net prices to growers being marginally less than production costs. The result of the lower basis is a smaller supply of corn for export.

[3] Wilson and Lakkakula (2021) provide a detailed comparison and documentation of these logistical costs in addition to those of the major competing countries.

Other factors contributing to this diminished supply include reduced access to inputs, workers, etc. Estimates for the corn-export supply vary, but supply generally decreased from 23.5 mmt in 2021 to 15 mmt projected for 2022/23, and current estimates (April 2023) for the 2023/24 exports range from 10 mmt to 15 mmt.

Policies That Affect International Corn Competition

Prior to the invasion, Ukraine had few policy interventions and was confronting land reform that was expected to increase productivity and competitiveness (Day, 2021; Polityuk, 2021; Van Trump Report, 2021; Verbyany and DeSusa, 2021). However, substantial trade interventions affect trade flows and competition in the global corn market.[4] Key trade policies include China's tariff-rate quota (TRQ), EU import restrictions for genetically engineered (GE) corn, the EU import tariff for imported corn, and Chinese sanitary and phytosanitary standards (SPS) for corn originating in Brazil and Argentina. The policies of particular importance to this study are the phytosanitary requirements for shipments from Brazil to China and the EU import tariffs.

China has traditionally used phytosanitary regulations for its corn imports that originated in Argentina and Brazil. These requirements must be met when trading corn in order to conform with the Chinese SPS restrictions. As a result, exports originating from Argentina and Brazil and going to China have been small. Immediately following the Russian invasion of Ukraine, China expedited a process to approve Brazil's phytosanitary procedures (Mano, 2023). These changes were approved and facilitated exports from Brazil to China; shipments commenced in November 2022.

Previous Studies

A few recent studies have analyzed the logistics and spatial competition among corn exporters in the international corn market. Meade et al. (2016) examined the export competitiveness of corn (and soybeans) from three countries: Argentina, Brazil, and the United States. The results indicated that the United States has an advantage with transportation costs, especially the inland transportation costs that include low-cost barge and rail transportation, compared to Argentina and Brazil. However, Ukraine had a low inland cost of transportation for corn when compared with the United States, Brazil, and Argentina. S&P Global Platts (2020) described the evolution of competition and the effects of new and expanding competitors. Kamrud, Wilson, and Bullock (2023) analyzed logistics competition for soybeans from interior US and Brazilian origins to China, suggesting that there were natural equilibrium seasonal market shares, although the portions were heavily affected by logistical costs and risks.

Mallory (2021) investigated the patterns for commodity exports from the United States and Brazil during the first wave of the COVID-19 pandemic in the United States. These studies illustrated the importance of logistical costs for export competitiveness. More recently, Padilla et al. (2023) studied US competitiveness for corn and pointed to the importance of free trade agreements with corn. They also indicated the growth in export competitiveness by Ukraine and Brazil in international corn when considering the effects of yield, land costs, transportation, exchange rates, efficiency, labor, and other factors, but these were not quantified.

The invasion of Ukraine had major implications for commodity flows, trade routes, and costs (UkrAgroConsult, 2022); grain storage (MacDonald and Grove, 2022); and food security (Eurasia Group, 2022). Recent studies have assessed the broader changes in agriculture and trade. In addition, recent studies suggested the prospective changes in trade and equilibrium trade (e.g., Ahn, Kim, and Steinbach, 2023; Steinbach, 2023, and papers presented at the 2022 International Agricultural Trade Research Consortium annual meeting). Bullock, Lakkakula, and Wilson (2023) analyzed how the invasion impacted international prices and Glauber (2023a,b) and Welsh (2023) described the invasion's impacts on food security.

[4] Wilson and Lakkakula (2021) describe, in detail, the trade-policy mechanisms that affect trade flows for corn.

Empirical Framework

Overview

Important features of the problem addressed in this study are that many logistical costs and functions, in addition to the import demand and export supply, are random. Export supply is compounded by short-term changes in production and/or capacity restrictions at ports; additionally, demands and some of the logistical costs are highly seasonal. For these reasons and given the purpose of this study, traditional equilibrium models are less appropriate and/or would be difficult to implement. Instead, we specify a stochastic, short-term, minimum-cost spatial network model in the spirit of recent, similar models (e.g., Skadberg et al., 2015; Kamrud, Wilson, and Bullock, 2023).

The specification is an optimized Monte Carlo simulation (OMCS) model and is used to derive optimal trade flows among origins and destinations under alternative scenarios (in this case, pre- and postinvasion). The model minimizes logistical costs through the network for trade flows from specific origins to specific destinations. The results should be interpreted as short-run trade flows resulting from a minimum cost specification, particularly relevant given the conflict. This interpretation differs from gravity models and traditional approaches of determining longer-run, market-equilibrium trade flows. Our specified OMCS model can be used to evaluate short-run changes in trade flows and shares among the origins and destinations. Important features of our problem that are not naturally included in gravity models are supply restrictions, random and correlated costs, and shipping costs, which are nonproportional with distance and whose relationship varies across routes.

The OMCS varies from traditional risk programming and Monte Carlo optimization because our primary goal is to use stochastic simulation to explore a set of plausible scenarios, which differs from optimization under conditions of risk and uncertainty (Schade and Wiesenthal, 2011). Further, we use short-term data that has seasonality and capacity restrictions in the export supply chain, and many of the variables are random. Taken together, this model allows us to capture spatial competition and trade flows given the distributions for prices and costs (Graubner, Ostapchuk, and Gagalyuk, 2021). To our knowledge, the OMCS model has not been used for previous studies examining agricultural trade flows, with the exception of Kamrud, Wilson, and Bullock (2023).

The OMCS assumes that the decision maker knows the *ex post* realized values for the random variables and then makes optimized decisions. The procedure generates new values for the random variables with each iteration (a Monte Carlo iteration), makes relevant calculations and determines the optimized decision based on the observed values.[5,6] These steps are repeated, and the results of the optimized iterations are summarized as a distribution of optimized choices. This approach differs from traditional risk programming and Monte Carlo optimization, in part because our focus is on determining plausible scenarios (Schade and Wiesenthal, 2011).

The logic of this framework is that the decision maker chooses trade flows to optimally minimize the global logistics costs in the system given a plausible, simulated set of costs and market parameters that were observed with certainty. The model generates a set of historically plausible cost/market scenarios given what has been observed in past behavior.

The OMCS specification is particularly appealing given the goal of this study and that the data are shorter term in duration, seasonal, highly random, and correlated. Many of the model's price and cost components are represented as linked (through correlations or regressions) stochastic distributions, allowing plausible historical or projected future scenarios to be determined. In summary, the OMCS model is appropriate for three reasons: (i) it is based on deterministic optimization, (ii) it has a large number of plausible scenarios; and (iii) the goal of this study is to isolate the effects of logistical costs and policies on trade flows, given the plausible scenarios as represented by the distributions of random variables.

---

[5] Model details are discussed in Figueira and Almada-Lobo (2014), where the techniques were referred to as sequential simulation-optimization (SSO) models.

[6] The OMCS was used previously by Kamrud, Wilson, and Bullock (2023). A detailed discussion of the data and steps used in the OMCS is available in Wilson, Lakkakula, and Bullock (2023).

Model Specification

We developed a stochastic optimization model of corn flows from Ukraine and other major exporters to major importers to determine the expected least-cost trade flows and to evaluate the effects of some critical parameters. The objective function was specified to minimize the global delivered costs for a number of origins to destination routes where the model determined the lowest cost on a monthly basis. Cost, insurance, and freight (CIF) prices were based on the approximate expenses, defined below, from each origin to each destination, multiplied by the amount of corn shipped. CIF prices were calculated as the sum of random ocean shipping costs from the origin port to the export destination plus the derived FOB price at the origin port. The model imposed multiple restrictions to capture the effects of supply and port capacities, along with the trade interventions that influence competition in these markets. Because the model uses Monte Carlo simulation, the technique's approximate comparative statics can be derived by utilizing advanced scenario and sensitivity analysis. The model used for this study was constructed by using the @Risk (Palisade Corporation, 2023) simulation add-in with Excel.

The model included 11 origins and 8 destinations (defined below). The optimization problem, which was solved for each iteration of the Monte Carlo simulation (with new, randomly generated scenario values), was specified as

$$\min_{q_{ij}} C = \sum_{i=1}^{11}\sum_{j=1}^{8} \tilde{c}_{ij} q_{ij}$$

subject to:

(1)
$$q_{ij} \geq 0$$

$$\sum_{j=1}^{8} q_{ij} \leq \widetilde{Q}_i \text{ for all } i = 1,\ldots,11 \text{ origins,}$$

$$\sum_{i=1}^{11} q_{ij} \geq \widetilde{D}_j \text{ for all } j = 1,\ldots,8 \text{ destinations.}$$

The objective was to minimize the total delivered cost across all trade flows from origins (i) to destinations (j) by selecting the optimal quantity for the trade flow ($q_i j$). In addition to the eight major destination regions, the remaining destinations were grouped together into a rest of world (ROW) category.

The first constraint restricted trade flows as positive values (i.e., no negative backflows from the destination to the origin). The second constraint required that the sum of the trade flows from the origins not exceed the randomly generated supply-capacity constraint value (Q_i) for each origin. The third constraint was that the sum of the flows to each destination be greater than or equal to the randomly generated demand (D_j) for that destination. To assure convergence of the optimization model, the ROW category was modeled as receiving any excess origin supply from each origin, provided that the origin supply constraint was not binding.

Additional constraints were imposed on the model to account for trade policies. The EU tariff on US crops was 25% and was added to the simulated p_{ij} values from US origins to the European Union. To reflect the existing phytosanitary restrictions on South American corn exports to China, a maximum share of 1% (of all flows to China) was applied to each origin's q_{ij} flow to China. For the phytosanitary restrictions on South American exports to the European Union, a similar constraint was applied, with a maximum share of 18% (of all flows to the European Union) for Brazil and 2% for Argentina.

The origins included three interior locations for each US export port (Gulf and PNW) and one export origin in Ukraine preinvasion and three routes postinvasion. There was one export port each for

Brazil and Argentina. For all US origins except for St. Louis, MO, the delivered price to a destination was calculated as follows:

$$\tilde{c}_{ij} = \tilde{b}_i + \tilde{r}_i + \tilde{v} + \tilde{e}_i + \tilde{o}_{ij}, \tag{2}$$

where i is the index for the origin location, j is the index for the destination, b is the nearby basis (cash minus CME futures), r is the sum of the railroad tariff and fuel surcharges from the origin to the export port, v is the rail's secondary-market railcar value, e is the elevation and handling costs, and o is the ocean freight from the origin export port to the destination. A tilde (~) indicates that the variable was generated using a Monte Carlo simulation to create a historically representable value. For the St. Louis origin, equation (2) was modified by replacing the railroad costs ($\tilde{r}_i + \tilde{v}$) with the barge rate ($\tilde{k}$) from St. Louis to the Gulf ports.

For Ukrainian origins, the secondary-railcar market value ($\tilde{v}$) was not included. For Brazil and Argentine origins, the $\tilde{c}_{ij}$ values represented the sum of the simulated port's FOB basis values ($\tilde{b}_{ij}$) plus the ocean freight ($\tilde{o}_{ij}$) to the destination, with all other variables in equation (2) set to 0.

Data Sources and Simulation Procedures

This study's focus was on corn shipments from origins in the United States, Ukraine, Brazil, and Argentina. The US origins were in six interior regions, with three regions shipping to the US Gulf ports and three regions shipping to the US PNW ports. For the US Gulf, the interior origins were Champaign, IL; Lincoln, NE; and St. Louis, MO. For the US PNW, the interior origins were Waite Park, MN; Jamestown, ND; and Sioux Falls, SD. Ukraine was delineated with three routes or ports: Odesa, Constanta (via the river/canal connecting Izmail, Ukraine, to Constanta, Romania) and Western Border (via the rail crossing into Poland). The destinations were China, Japan, Indonesia, the European Union, South Korea, Vietnam, North Africa, and the Middle East. To avoid cases with 0 trade volumes, specific country destinations were aggregated under the following groupings: North Africa (Algeria, Egypt, Libya, Morocco, Tunisia, Mauritania, Sudan, Egypt, Morocco, and Algeria) and the Middle East (Iraq, Syria, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, the United Arab Emirates, Yemen, and Bahrain).

Historical monthly data were used to estimate basis and cost distributions between January 2017 and December 2022. The variables and their sources are listed in Table 2. For the United States, the cost elements at each inland suborigin were basis, daily car values, the rail tariff, the fuel service charge, barge rates, and interior/port elevation costs. For Ukraine, the costs included basis, the rail tariff, and interior/port elevation costs. The expenses for shipments from Brazil and Argentina were based on the historical FOB port basis. Data for ocean rates were developed for each origin–destination combination. The costs from the US Gulf (via the associated interior origins) to the European Union included an additional 25% tariff. Statistical procedures were utilized to determine the best distribution for each random variable in the Monte Carlo simulation.[7]

Simulation of US Interior Logistics and Handling Costs

Data for the daily car values (DCV) series indicated that it is highly volatile with fat, upward tails. Application of statistical tests (Shapiro–Wilk, Anderson–Darling, Lilliefors, and Jarque–Bera) to the data all clearly rejected normality. Therefore, the @Risk *Bestfit* procedure was used to find the best-fitting distribution(s) for the historical data. The plot indicated that no particular distribution dominated; therefore, a weighted simulation was set up, where the global DCV value ($\tilde{v}$ in equation 2) had an equal probability (0.333) of being simulated from any of the three distributions when utilizing a discrete distribution.

[7] The specification of all distributions for this study is too large to report here but is available from the authors on request.

Table 2. Variables and Data Sources

Variable	Source
US interior basis, prices and futures price	Data Transmission Network (2023); TR-Eikon (2021)
US rail tariff and fuel service charge	Burlington Northern & Santa Fe Railway; US Department of Agriculture (2019–2021)
US daily car values	TradeWest Brokerage (2013–2022)
US barge rates and tariffs	US Department of Agriculture (2019–2021)
US and Ukraine's export elevation	Industry sources and represented as distributions
Ukraine farm prices and basis	US Department of Agriculture (2019–2021)
Ocean freight cost for all origin-destination pairs	TR-Eikon (2021)
Ukrainian elevator-handling data at origin ports	Industry sources
Ukrainian rail shipping cost	Industry sources
Brazilian and Argentinian free-on-board (FOB) basis	AgriCensus (2021)
Trade flows	United Nations (2021): Ukraine, Brazil, Argentina and the world. US Department of Agriculture (2022, 2019–2021); Data Transmission Network (2023) : US ports' (US Gulf and US PNW) export flows. European Union (2022): European Union

Barge rates from St. Louis, MO, to New Orleans, LA, were specified as an index multiple of the base tariff rate. To test for the presence of a trend and seasonality, the following analysis of covariance regression model was fitted to the historical index data:

$$(3) \qquad k_t = \alpha + \theta \times year(t) + \sum_{j=1}^{11} \delta_j \times M_j + \varepsilon_t,$$

where k_t is the monthly average barge-rate index, $year(t)$ is the calendar year, M_j is seasonal dummy variables (equal to 1 if $month(t) = j$) and ε_t is *i.i.d.* normally distributed standard errors. To correct for heteroskedasticity and autocorrelation in the time series, the Newey–West procedure (lag = 1 month) was applied when estimating equation (3). F-tests using the Type III sum of squares from the regression statistically supported the presence of both a trend and seasonality in the time series. To simulate a particular barge-index observation, a normal random variable with a mean equal to 0 and a standard deviation equal to the regression root mean squared error (RMSE) was used to simulate the residual error term ($\tilde{\varepsilon}_t$); then, the simulated value ($\tilde{k}_t$) was derived from equation (3), given a particular year and month.

A similar regression model was fitted to the rail tariff plus fuel surcharge ($r_{i,t}$) data for each US rail origin. The F-tests using Type III sum of squares rejected the presence of seasonality but supported a trend. The following equation was fitted for each origin series:

$$(4) \qquad r_{i,t} = \alpha + \theta \times year(t) + \varepsilon_{i,t}.$$

A related procedure was utilized to simulate each residual error term ($\tilde{\varepsilon}_{i,t}$) by using a normal distribution with a mean of 0 and a standard deviation equal to the RMSE. The random residual was then incorporated into equation (4) to provide the simulated value of each origin rail rate plus the fuel surcharge ($\tilde{r}_{i,t}$).

Historical data do not exist for US interior elevation and handling costs (e_i), with the same holding true at the US Gulf and the US PNW. Therefore, expert opinions were solicited to provide the most likely values for the interior ($0.35/bushel) and port ($6.69/mt) values. To simulate the uncertainty, a triangular distribution was used, with the mode set to the expert-opinion values and a min/max range set at 10% of the modal value.

Simulation of US Interior and South American Basis Values

Historical basis values ($b_{i,t}$) were derived from historical interior spot-cash prices for US origins or port FOB values for South American origins. Fitting a form of equation (3) (with trend and seasonal dummies), an examination of the F-tests using the Type III sum of squares indicated the presence of seasonality and trend in most of the series. The following equation was estimated for each basis series:

$$b_{i,t} = \alpha + \theta \times year(t) + \sum_{j=1}^{11} \delta_j \times M_j + \varepsilon_{i,t}, \tag{5}$$

where all of the variables are as defined in equation (4). To simulate the random basis values ($\tilde{b}_{i,t}$), the random residual values ($\tilde{\varepsilon}_{i,t}$) were simulated as a normal random variable with a mean of 0 and a standard deviation equal to the regression RMSE, and equation (5) was used to simulate the corresponding basis value.

Simulation of Ukraine's Interior Basis, Logistics and Handling Values

Data about interior Ukrainian basis values were not readily available, with the exception of some limited quarterly data for Central Ukraine cash corn prices from Q3 2019 through Q3 2022. The data from Q3 2019 to Q1 2022 were used for the period prior to the Russian invasion, and the Q2 2022 and Q3 2022 observations were utilized for the period subsequent to and following the conflict's onset. The preinvasion distribution for basis was estimated by utilizing the @Risk *Bestfit* procedure. There was no consistency across the information (Akaike and Bayesian) and the statistical (Kolmogorov–Smirnov and Anderson–Darling) criteria in terms of recommending a single best-fitting distribution. To simulate the basis values, the three recommended distributions were combined using a discrete distribution with a 0.333 probability of each distribution providing the simulated value. For the postconflict period, the utilized distribution was uniform with the minimum and maximum values provided by the two observations.

Data were developed from discussions with traders about Ukrainian logistical and handling costs and were then used to specify the most likely (modal) values. Table 1 summarizes this information, which was discussed previously. To account for uncertainty, triangular distributions and a min/max range of ±10% of the modal values were utilized to simulate the costs.

Simulation of the Ocean Shipping Rates

Data on monthly average ocean shipping rates were available for 30 routes. Partial (1–2 years) data were available for an additional 19 routes. Because there were no export flows from the US PNW to Egypt, North Africa, and the Middle East, the elements of the delivered cost for these flows were specified at a prohibitively high value ($10,000/mt) to exclude these trade flows under all but the most extreme conditions.

Table 3 shows the correlation for ocean rates for selected routes. The Spearman rank-order correlation matrix of the variables shows a strong, positive correlation between all series with a high degree of statistical significance. Regressions of the ocean rates on Brent crude oil prices and the Baltic Dry Index (BDI) produced R^2 statistics ranging from 83.3% to 91.0%, indicating that a high percentage of variation with the ocean rates was explained by the Brent and BDI variables. Therefore, the following regression equation was fitted to each individual ocean-rate series:

$$o_{ij,t} = \alpha + \beta_1 \times Brent_t + \beta_2 \times BDI_t + \varepsilon_{ij,t}. \tag{6}$$

Fitting trend-seasonal models with the same form as equation (3) to both Brent and BDI and then applying the F-tests only supported the trend component of the model without seasonality. The

Table 3. Spearman Rank-Order Correlation Matrix for Brent Crude (Brent), Baltic Dry Freight Index (BDI), and Selected Ocean Shipping Rates for Major Origin–Destination Pairings

Variables	Brent	BDI	USG to EU	PNW to JPN	ARG to CHINA	BRZ to EU	UKR to CHINA
Brent	1	0.4356	0.6718	0.8024	0.6563	0.6835	0.6293
BDI	0.4356	1	0.8298	0.6966	0.8299	0.8224	0.7725
USG to EU	0.6718	0.8298	1	0.8354	0.9613	0.9988	0.8522
PNW to JPN	0.8024	0.6966	0.8354	1	0.8408	0.8420	0.7893
ARG to CHINA	0.6563	0.8299	0.9613	0.8408	1	0.9626	0.8869
BRZ to EU	0.6835	0.8224	0.9988	0.8420	0.9626	1	0.8526
UKR to CHINA	0.6293	0.7725	0.8522	0.7893	0.8869	0.8526	1

Notes: All values at different from 0 with a significance level of $\alpha = 0.05$. Results indicate a significantly high level of rank-order correlation between the ocean rates, crude oil prices (Brent), and major ocean shipping cost indices (BDI) for dry goods. This provided confidence in modeling ocean rates using linear regression upon Brent and BDI for Monte Carlo simulation purposes.

following regression models were used to estimate the simulation values for both variables:

$$\begin{aligned} Brent_t &= \alpha + \theta \times year(t) + \varepsilon_t, \\ BDI_t &= \alpha + \theta \times year(t) + \varepsilon_t. \end{aligned} \tag{7}$$

Simulated values of both Brent and BDI ($\widetilde{Brent_t}$ and $\widetilde{BDI_t}$) were generated by utilizing the formulae in equation (7), with randomly generated error terms using a normal distribution with a mean of 0 and a standard deviation equal to the equation's RMSE. The modeled values for each ocean rate were generated by plugging the simulated values of Brent and BDI into equation (6) along with a randomly generated error term using a normal distribution with a mean of 0 and a standard deviation equal to the RMSE in equation (6).

Supply-Capacity Constraint for Export Flows

Ideally, a capacity constraint would be specified for each function: grain supply, handling, and shipping capacity. However, this option was not possible for numerous reasons. As an alternative, we specified a "supply-capacity constraint" for each origin region to restrict flows to the historical distribution, which constrains the export volume from particular flows to conform to historical distributions. This supply-capacity constraint is a random distribution of the functions described above, but if the constraint is restrictive, we can infer the share of shipments that are diverted to alternative origins.

The supply-capacity constraints were derived for each export port (US Gulf, US PNW, Ukraine, Argentina, and Brazil) by utilizing monthly total corn exports from January 2017 to December 2021. For the US ports (Gulf and PNW), the simulated port capacities were allocated to the corresponding origin regions based on historical production shares (using data from the ProExporter Network, 2022) for those regions during the 2015/16–2020/21 marketing years. For the US Gulf, the historical shares were 35.0% from Lincoln, NE; 10.3% from St. Louis, MO; and 54.7% from Champaign, IL. For the US PNW, the historical shares were 14.4% from Kensal, ND; 20.2% from Sioux Falls, SD; and 65.4% from Waite Park, MN.

To simulate each individual capacity constraint, a combined trend-seasonal dummy regression equation, of the form in equation (3), was fitted to each series. F-tests confirmed the significance of both the trend and seasonal variables; therefore, the following regression models were estimated for each port capacity:

(8) $$Q_{i,t} = \alpha + \theta \times year(t) + \sum_{j=1}^{11} M_j + \varepsilon_{i,t}.$$

The random supply capacities ($\tilde{Q}_i$) were obtained by simulating the residual term ($\tilde{\varepsilon}_{i,t}$) as a random normal variable, with a mean equal to 0 and a standard deviation equal to the regression RMSE, and then plugging it into equation (8).

Country and Regional Import Demands

Distributions of the import demands were derived similarly. Trend-seasonal dummy regression tests supported both the presence of a significant trend and seasonal components. Regression equations of the same form as equation (8) were fitted with the country regional demands ($D_{j,t}$) as the dependent variables. Randomly simulated residuals were then incorporated into the regression equation to simulate the random demands.

Results and Sensitivity Analysis

The model was simulated for both the pre- and postinvasion periods. The fundamental difference between these periods related to logistical costs, routes, and constraints as well as ocean shipping and Grain Corridor costs. In addition, the export supply constraint in the postinvasion period reflected the distribution for expected exports in 2023. The model determined the minimum-cost trade flows, and the results should be considered as short-term. Longer-term projections would be difficult to derive. The model was solved for each month and then aggregated for the market year. The model derives trade flows which were used to derive market shares, reported below. The results represent the logistical competitive advantage of each specific origin with regards to each major export destination.

The base-case scenario reflected the spatial competitive conditions and the market shares for major players in the global corn market during the preinvasion period from 2015 through February 2022. Restrictions, in addition to constraints, were imposed for trade policies to reflect China's sanitary and phytosanitary standards and the European Union's restrictions on genetically engineered corn imports from these origins. A constraint was not imposed on US corn exports to the European Union because of the Abatimento agreement with Spain and Portugal, through which most of the US corn can be delivered to the European Union (European Commission, 2007). The Abatimento agreement allows Spain and Portugal to import up to 2 mmt and 0.5 mmt, respectively, of corn from any country without import tariffs. Given the historical nature of the agreement, most US corn exports to the European Union go to Spain and Portugal.

Figure 1 shows the probability distributions for the total cost from each origin port to China. Similar distributions were derived for each month as well as pre- and postinvasion for each demand region/country. These costs include the relevant basis and all relevant logistical costs, as described above. On average, Ukraine has the highest delivered costs and Argentina is the lowest. The US PNW has the lowest standard deviation and the values for Ukraine, Brazil, and Argentina are greater. These distributions have substantial overlap. The Monte Carlo procedures' iterations can draw samples from origins that differ from these means. The effect of these overlapping distributions results in intense competition across origins and, in addition, provides an explanation about why buyers make purchases from multiple origins during the same period. This finding is an important empirical result that affects the distribution of trade flows shown below and is observed in practice when importing countries frequently buy from different origins.

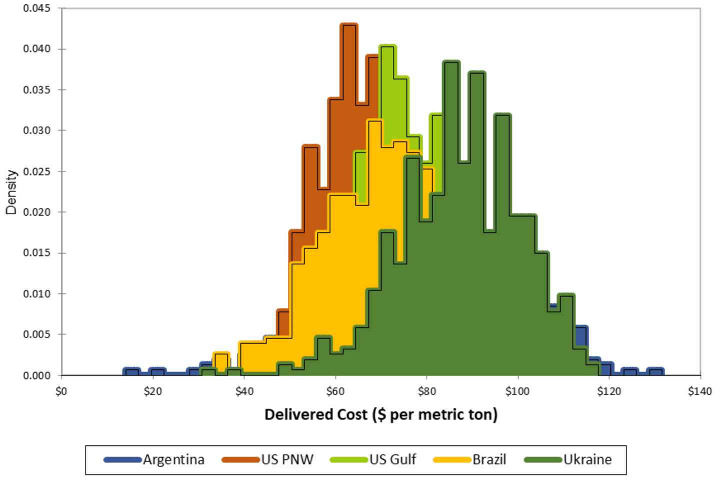

Figure 1. Probability Distribution of the Total Costs from Different Origins to China: Pre-Invasion for November

Notes: The probability distribution for logistics costs and basis are shown for November preinvasion shipments to China from each origin. It is important that (i) Ukraine has the highest mean cost and Argentina has the lowest, (ii) the US PNW has the lowest standard deviation while Argentina has the highest; and (iii) the distributions are all overlapping each other resulting in intense international competition.

Preinvasion: Results for the Least Cost Trade Flows

Table 4 shows the annual market shares of the trade flows for each origin–destination combination for the preinvasion base case. The 90% confidence intervals were estimated using a Dirichlet distribution with 550 observations (i.e., iterations). The reason for using the Dirichlet distribution is that the market shares are nonnormal and always sum to 100%. Also, the Dirichlet is the Bayesian prior distribution for multiple probabilities (shares).

The US Gulf dominates Chinese imports, the US PNW dominates Japanese imports, and Ukraine dominates EU imports. Brazil dominates the Middle East corn markets, while Argentina dominates the Vietnamese, Indonesian, and North African markets. It is of interest that each destination imports corn from multiple exporters. The reasons for this result include, first, that the export origins are highly competitive and that the Monte-Carlo simulation allows for purchases to be shifted among origins based on the overlapping cost distributions (as discussed above). Second, demand—as well as some of the logistical costs—is seasonal and would result in importers shifting among suppliers.

The results can be interpreted as the likelihood that a specific flow is the lowest cost. The probability that the US Gulf is the least costly origin for China is 0.47, and Brazil is the least costly origin for South Korea, with a probability of 0.42. The US PNW would be the least costly origin for Japan. Ukraine would, by far, be the least costly origin for the European Union and would be highly competitive in Indonesia and China.

The supply-capacity constraint is an important logistical restriction. The constraint is random and, if binding for any iteration, has the effect of diverting shipments to an alternative origin. Technically, this constraint is random and represents the maximum amount of corn exports that can be shipped during a given month. This random constraint differs from a physical export-capacity restriction, which would have to account for the handling of other crops as well as the physical limits of the export infrastructure. Nevertheless, the results provide a high-level interpretation of the export capacity. The supply-capacity constraints indicate the percentage of iterations that hit the capacity limit imposed on the model. A supply constraint of interest is that, for the US PNW, which implies that in 50.8% of the iterations, the export capacity was reached, and that shipments would be diverted to other origins. The other value of interest is that the result for Ukraine was 47.%5 and for Brazil was 43%. Overall, these findings suggest prospective supply-capacity limits, notably with the US PNW, Ukraine, and Brazil.

Table 4. Pre-Invasion Simulation Destination Market Shares by Origin

	Origins and Share of Destination (%)					
Destinations	**US Gulf**	**US PNW**	**US Total**	**Ukraine**	**Brazil**	**Argentina**
China	47.3 (43.9, 50.8)	35.4 (32.0, 38.9)	82.7 (75.8, 89.6)	15.8 (13.3, 18.3)	0.8 (0.3, 1.5)	0.7 (0.2, 1.4)
Japan	7.8 (6.0, 9.7)	29.3 (26.2, 32.5)	37.1 (32.2, 42.3)	8.1 (6.3, 10.1)	19.7 (16.9, 22.5)	35.1 (31.8, 38.5)
Indonesia	7.6 (5.8, 9.6)	7.6 (5.8, 9.6)	15.2 (11.7, 19.1)	20.8 (18.1, 23.7)	24.0 (21.0, 27.0)	40.0 (36.6, 43.5)
The EU	14.2 (11.8, 16.6)	0.0 (0.0, 0.0)	14.2 (11.8, 16.6)	68.7 (65.6, 71.9)	15.2 (12.8, 17.8)	1.9 (1.1, 3.0)
South Korea	12.0 (9.8, 14.4)	12.0 (9.8, 14.3)	24.0 (19.6, 28.8)	4.2 (2.9, 5.8)	41.8 (38.4, 45.1)	30.0 (26.8, 33.3)
Vietnam	1.2 (0.5, 2.1)	4.6 (3.3, 6.2)	5.8 (3.8, 8.2)	1.6 (0.8, 2.6)	39.3 (35.7, 42.7)	53.3 (49.7, 56.9)
North Africa	14.4 (12.1, 16.9)	0.0 (0.0, 0.0)	14.4 (12.1, 16.9)	5.8 (4.2, 7.5)	1.0 (0.4, 1.8)	78.8 (75.9, 81.6)
Middle East	1.6 (0.8, 2.5)	0.0 (0.0, 0.0)	1.6 (0.8, 2.5)	16.4 (13.8, 19.0)	63.3 (59.9, 66.7)	18.7 (16.0, 21.6)
ROW	44.8 (41.4, 48.3)	4.3 (3.0, 5.8)	49.1 (44.4, 54.1)	12.2 (10.0, 14.5)	21.7 (18.9, 24.7)	17.0 (14.4, 19.7)
Prob Supply Constrained	2.6	50.8	2.2	47.5	43.0	37.8

Notes: Values in parentheses are approximated 90% confidence intervals. Probability Supply constrained represents the percentage of iterations where the origin supply constraint was binding (i.e., was at max capacity).

The preinvasion base case shows the percentage share of the major destination markets (rows) for each export origin (columns) in the model. The US Total is the sum of the Gulf and PNW market shares; therefore, for each row, the values for US Total, Ukraine, Brazil, and Argentina sum to 100%. The bottom row shows the percentage of simulation iterations where the export origin reached its total capacity (simulated based upon historical shipments) constraint for a particular month.

The United States has a dominant share of the Chinese and Rest of World (ROW) markets while splitting the Japanese market with Argentina. Ukraine has a dominant share of the European Union (EU) market, Brazil dominates the Middle East, while Argentina dominates the North African and Vietnamese markets with a significant share of the Indonesian market. The export supply capacity constraint was binding over half of the iterations for the US PNW, an indication that with greater capacity, exports through that port would increase. The same holds to a lesser extent for the Ukraine, Brazil, and Argentina origins. The only port with significant excess capacity is the US Gulf.

Postinvasion: Results for the Least Cost Trade Flows

During the postinvasion period, there were changes in logistical costs, routes, and capacity; both Odesa's ocean rates and Grain Corridor costs rose. These changes were in addition to the relaxed phytosanitary restrictions on Brazilian corn exports to China.

Table 5 reports the market share results and Figure 2 illustrates the change in market share (from preinvasion scenario). One of the most important changes is the increase in Brazil's share to China from nearly 0 to 68%. These shipments are taken from the US Gulf, the US PNW, and Ukraine. Brazil would be the lowest-cost supplier to China, with a probability of 0.679, and that value from Ukraine would be 0.048. Due to Brazil's shipments to China, Brazil loses market shares in all other markets. Ukraine loses market shares in every region except Indonesia and the Middle East. In this scenario, the United States would dominate only Japan.

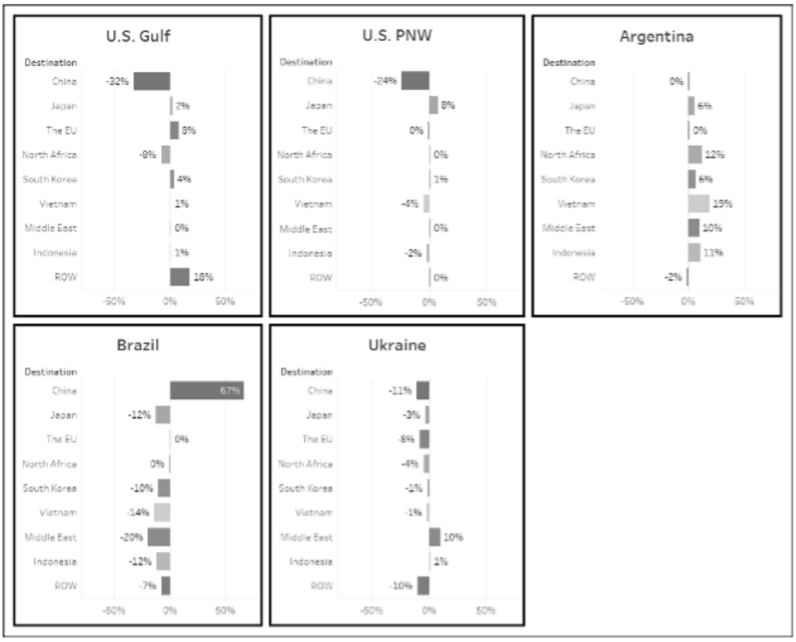

Figure 2. Change in Export Market Shares between Pre-Invasion and Post-Invasion Scenarios

Notes: This figure shows the change in export market shares for the major five exporters when going from the preinvasion to the postinvasion scenarios (including relaxation of Chinese phytosanitary restrictions on Brazilian corn). These results illustrate the major impact that the Chinese phytosanitary policy change has on Brazilian and US corn export shares. Argentina becomes the primary beneficiary of the invasion as it gains significant shares of these remaining markets. Ukraine loses some its dominant share of the EU market which primarily is to the benefit of the US Gulf. Both the US PNW and Argentina pick up most of Brazil's reduced share of the Japanese market. The US Gulf picks up a significant share of the Rest of World (ROW) market at the expense of Brazil and Ukraine.c

The frequency that the supply capacity restriction is binding changes sharply. The value for the US PNW increases to 55%, and the values for Ukraine and Brazil increase to 81% and 60%, respectively. As a result of these changes, Ukraine's frequency of being at capacity has increased, as has Brazil's. This result is due to the combined effects of Ukraine's reduced export supplies as well as capacity constraints at the alternative export ports, inclusive of the Grain Corridor's influence. The increased value for Brazil is due primarily to the country's increased exports to China.

Postinvasion: Sensitivities

We conducted simulations under alternative assumptions to isolate the effects of specific variables. One of the most important changes was the relaxation of phytosanitary restrictions on Brazil's shipments to China. These results were shown above, but that change was concurrent with many other important variations. To isolate the effect of this SPS policy, the postinvasion model was run with and without the restrictions. Figure 3 illustrates the results. These effects were drastic. Brazil's market shares increased sharply, and shares fell for the US Gulf and the US PNW as well as for Ukraine. Other changes included reductions in Brazil's shipments to all other markets. Ukraine and Argentina increased shipments to the Middle East; the US Gulf and the US PNW had more shipments to South Korea; and Argentina sent more shipments to South Korea and Vietnam.

During the postinvasion period, three routes were operating for Ukrainian shipments—Odesa, Constanta and rail through Poland—and they differed, in part, by the capacity restrictions as well as costs and by ocean shipping costs from each origin (Table 1). The postinvasion distribution for Ukrainian shipments was mostly from Odesa and Constanta, on average. The reason for this result is

Table 5. Post-Invasion Simulation Destination Market Shares by Origin

	Origins and Share of Destination (%)					
Destinations	**US Gulf**	**US PNW**	**US Total**	**Ukraine**	**Brazil**	**Argentina**
China	14.9 (12.4, 17.4)	11.9 (9.7, 14.3)	26.8 (22.1, 31.7)	4.8 (3.4, 6.4)	67.8 (64.5, 71.1)	0.6 (0.2, 1.2)
Japan	10.0 (7.9, 12.2)	37.1 (33.7, 40.6)	47.1 (41.6, 52.8)	5.0 (3.6, 6.6)	7.3 (5.6, 9.3)	40.6 (37.1, 44.1)
Indonesia	8.8 (6.9, 10.8)	5.9 (4.3, 7.6)	14.7 (11.2, 18.5)	22.2 (19.3, 25.2)	12.4 (10.1, 14.8)	50.7 (47.3, 54.1)
The EU	22.1 (19.3, 25.0)	0.0 (0.0, 0.0)	22.1 (19.3, 25.0)	60.7 (57.2, 64.1)	15.2 (12.8, 17.9)	2.0 (1.1, 3.1)
South Korea	15.8 (13.3, 18.4)	13.0 (10.8, 15.4)	28.8 (24.1, 33.9)	3.4 (2.2, 4.8)	31.5 (28.3, 34.9)	36.3 (33.0, 39.6)
Vietnam	1.8 (1.0, 2.8)	0.1 (0.0, 0.4)	1.9 (1.0, 3.2)	0.1 (0.0, 0.4)	25.8 (22.7, 28.9)	72.2 (69.0, 75.3)
North Africa	6.7 (5.0, 8.6)	0.0 (0.0, 0.0)	6.7 (5.0, 8.6)	1.5 (0.7, 2.4)	0.6 (0.2, 1.2)	91.2 (89.2, 93.2)
Middle East	1.9 (1.0, 3.0)	0.0 (0.0, 0.0)	1.9 (1.0, 3.0)	26.2 (23.2, 29.4)	43.4 (39.9, 47.0)	28.5 (25.4, 31.7)
ROW	63.2 (59.8, 66.7)	4.7 (3.3, 6.3)	67.9 (63.1, 72.9)	2.2 (1.3, 3.3)	14.5 (12.1, 17.0)	15.4 (13.0, 17.9)
Prob Supply Constrained	0.8	55.1	0.7	80.6	60.2	47.5

Notes: Values in parentheses are approximated 90% confidence intervals. Probability supply constrained represents the percentage of iterations where the origin supply constraint was binding (i.e., was at max capacity).
The postinvasion model also incorporates the lifting of phytosanitary restrictions by China on Brazilian corn imports. The results show the percentage share of the major destination markets (rows) for each export origin (columns) in the model. The US Total is the sum of the Gulf and PNW market shares; therefore, for each row, the values for US Total, Ukraine, Brazil, and Argentina sum to 100%. The bottom row shows the percentage of simulation iterations where the export origin reached its total capacity (simulated based upon historical shipments) constraint for a particular month.

The United States loses its dominance of the Chinese market, which is captured by Brazil. The United States maintains and increases its dominant share of the Rest of World (ROW) market while continuing to split share of the Japanese market with Argentina. Ukraine maintains its dominance in the European Union (EU) market and Argentina increases its dominance of the North African, Vietnamese, and Indonesian markets. Brazil's dominance of the Middle East market is lessened as it ships more to China.

due in part to the reduced export supply as well as Poland having a slightly greater ocean shipping cost. Without the corridor fee, Odesa was the dominant origin. With the corridor fee, some of the Odesa shipments to the European Union were shifted to Constanta (which dominated the EU market).

One of the costs incurred for shipments from Odesa was a corridor fee. This fee accounts for the added expenses of smaller ships, war and commodity insurance, demurrage, and other costs related to inspections; this fee may or may not be transitory. Eliminating this cost affects export-market shares. The most important change is that the shipments from Ukraine to China, Japan, Indonesia, South Korea, and the Middle East increase slightly while shipments to the European Union decrease slightly. There are only minor adjustments for shipments from the other origins.

Odesa plays a critical role in exports from Ukraine and for the world, in part because of low costs in the prewar period. In the postwar period, Odesa remained the low-cost, albeit constrained, option. Further, Odesa was bombed on more than one occasion. The model was restricted so that exports from Odesa would be nil (Figure 4). It is notable that, if Odesa were closed, virtually all Ukraine shipments

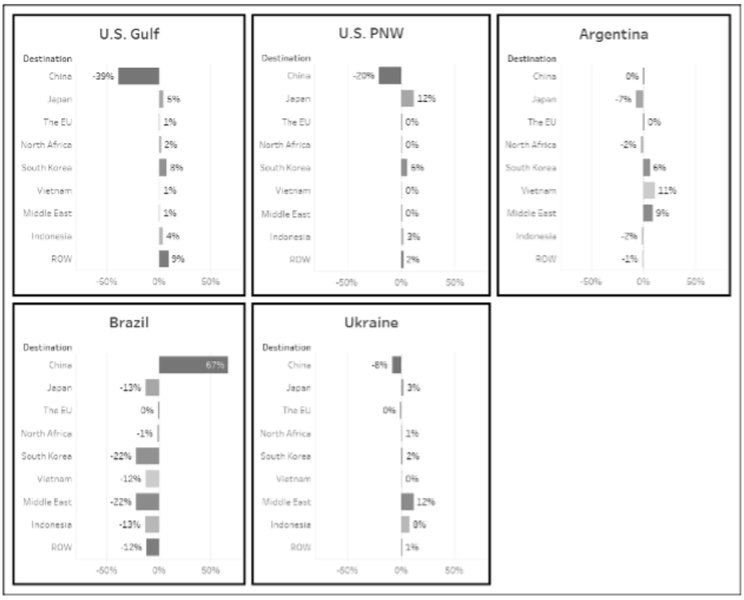

Figure 3. Changes in Post-Invasion Export Market Shares Due to Removing China's Phytosanitary Restrictions

Notes: This figure shows the impact of the assumption that China removes its phytosanitary restrictions on Brazilian corn imports relative to the postinvasion baseline (Table 5). The results indicate that Brazil would achieve a significantly higher (increase of 67%) share of the Chinese market at the primary expense of the US Gulf and PNW and, to a lesser extent, Ukraine. The results also indicate that Brazil would shift aware from other markets, particularly South Korea and the Middle East with Argentina and Ukraine as the primary beneficiaries..

would be diverted to Constanta, up to its capacity, and less than 1% would be shipped through the western border.[8] Shipments from the United States to China, Japan, and Indonesia would increase, as would shipments from Brazil to the Middle East and from Argentina to Indonesia and the Middle East. Shipments from Ukraine to just about all markets, except the European Union, would decrease. Thus, operations at Odesa are critical and this simulation represents most closely the operating conditions following Russia withdrawing from the Grain Corridor Agreement.

An important issue for the Grain Corridor Agreement negotiations is the disposition of grain for exports from Odesa. The intent of the Grain Corridor was, in part, to ensure that shipments were sent to lesser-developed countries in Africa and the Middle East. In actuality, the dominant destinations were China and the European Union (Spain and Turkey). This result is exactly what our postwar base case suggested as the least costly trade flows. In reality, one of Russia's negotiating points is the distribution of exports. To evaluate this influence, we restricted the model so that Odesa (the origin for the Grain Corridor) could not ship to EU destinations. The results were minor. Ukraine would continue shipping to the European Union but would shift its shipments to originate at Constanta, which is not part of the Grain Corridor.

Finally, to explore the potential effects if Ukraine were to return to normal, we specified the postwar model. Specifically, we allowed Ukraine to have export supplies the same as in the prewar scenario. All other changes for the trade policies and logistics remained at postwar levels. The results, shown in Figure 5, are drastic. Compared to the postwar base case, Ukrainian shipments increased to all destinations, including notable increases to China, Japan, Indonesia, the European Union, South Korea, and the Middle East. In contrast, shipments were reduced from the US Gulf, the US PNW, Brazil, and Argentina.

---

[8] In fact, this is exactly what transpired in Summer 2023. Refinitiv (2023) described specific details of changes in shipments through Constanta, including its costs and capacity restrictions in Summer 2023. Wilson, Lakkakula, and Bullock (2023) report further and more detailed simulations.

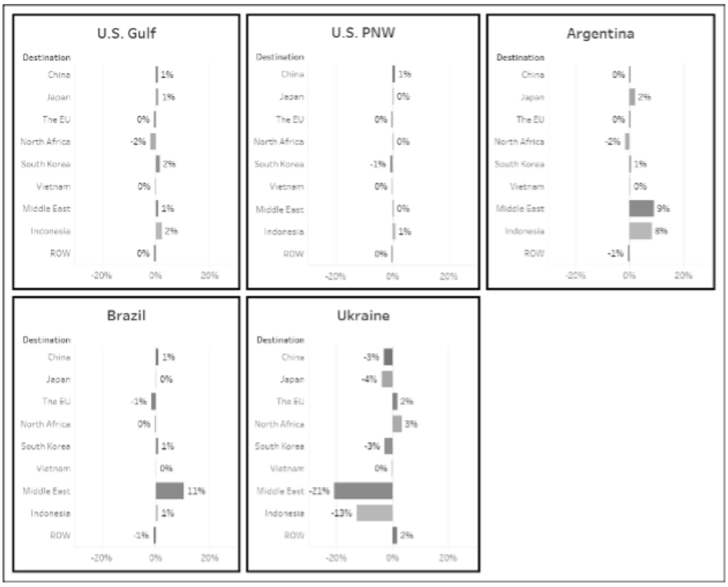

Figure 4. Change in Post-War Export Market Shares under Assumption that Exports out of Odesa Are Restricted to Zero

Notes: This figure shows the impact of the assumption that the exports out of Odesa (which also includes ports of Chornomorsk and Yuzhny/Pivdennyi) are reduced to 0 (most likely due to suspension of the Black Sea grain export corridor deal) relative to the postinvasion baseline. The results indicate that Ukraine would sharply reduce its share of the Asian and Middle East markets with a slight increase in share to the EU and North Africa. Ukraine shifts to its alternative routes through Constanta, Romania, (via waterways) and its Western Border (via rail). Argentina and Brazil would assume most of Ukraine's reduced share of the Middle East and Asian markets with the United States also gaining a marginal share of these markets.

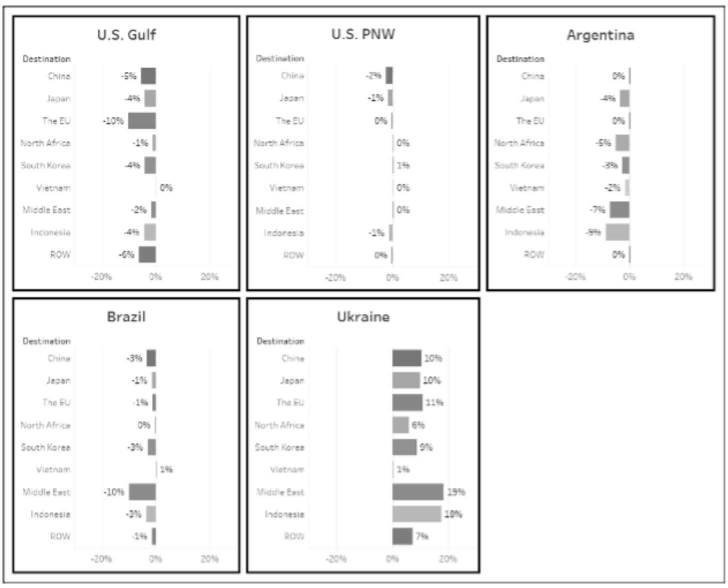

Figure 5. Change in Post-Invasion Export Market Shares under Assumption that Ukrainian Exportable Supplies Are Set at Pre-Invasion Levels

Notes: This figure shows the impact of the assumption that that Ukrainian corn production is increased to preinvasion levels, relative to the baseline postinvasion share (Table 5). The results indicate that Ukraine would recover significant market shares across all markets with the exception of Vietnam. This would come primarily at the expense of the US Gulf, Argentina, and Brazil with a minor impact upon the US PNW share of the Chinese and Japanese markets.

Summary and Policy Implications

The purpose of this paper was to analyze the influence of logistical costs and functions on US and Ukrainian global corn-market shares. Our focus was on corn flows from the United States and Ukraine to the major importing countries and regions. The model focused on the short run and minimized the total cost subject to constraints. The problem was analyzed using an optimized Monte Carlo simulation model, which is novel and allows for random variables, notably logistical costs and constraints, which are endemic and characteristic of the problem addressed in this study.

An important result was that, during the preinvasion period, the United States had a logistical comparative advantage to serve China and Japan. The US Gulf was the dominant port for export shipments to China, and the US PNW had an advantage for shipments to Japan. Ukraine had a logistical comparative advantage to the European Union. Brazil and Argentina had reduced market shares due in part to China's SPS policy. In the postinvasion period, the United States would dominate only Japan, and Ukraine would dominate only the European Union. Brazil would dominate China and the Middle East, and Argentina would capture the dominant share for the other markets.

Several changes occurred during the postinvasion period and are illustrated in these results. First, China's near-simultaneous approval of Brazil's phytosanitary procedures caused one of the most drastic changes in trade flows, diverting shipments from the US Gulf, US PNW, and Ukraine to Brazil. Second, most of the postinvasion shipments were from Odesa and Constanta due in part to the lower cost of these pathways relative to alternative routes. Odesa remained critical not only for capacity but also because it had a lower cost than alternative routes. If Odesa were closed, some Ukrainian shipments would be diverted to originate from the United States and Brazil. The Grain Corridor is an important intervention that facilitates trade. Despite the fact that the corridor's intent was to provide grain to Africa and other low-income countries, these results indicated that most shipments from Ukraine would be routed to the European Union. Finally, if Ukraine were able to revert to its previous distribution of export supplies, there would be drastic revisions to the least-cost trade flows.

Several implications can be drawn from this study's results. First, the findings indicate that international corn trade is extremely competitive, especially with multiple origins capable of supplying most import markets. The results illustrate that most import countries would optimally buy from multiple origins, likely due to the overlapping logistical cost distributions. The US Gulf and PNW should be the dominant origins for corn shipments to China, differing somewhat from observed shipments during the base period, when Ukraine was the dominant supplier. While there were many reasons for this distinction, important factors likely include (i) China's goal of diversification, (ii) nonprice preference for non-US-origin corn, and (iii) the apparent nontransparency of Ukraine's export marketing.[9]

There are several trade implications from the invasion of Ukraine that could lead to long-lasting effects, but these are dependent on (i) whether Odesa reverts to its previous capacity and costs, (ii) the cost and capacity of alternative routes for Ukrainian grain, (iii) the elevated ocean shipping rates through alternative routes and (iv) the capacity limits (constraints) for shipments through these routes and at those specific ports. The Grain Corridor has emerged as important for world trade and price volatility. These results illustrate the effects of the added costs due to the corridor's actions. The results also show that, postinvasion, a natural trade flow is through the Grain Corridor from Odesa to the European Union. This result has been a source of controversy in corridor negotiations because the intent was, in part, to facilitate trade in order to alleviate food shortages in poorer countries.

Finally, the implications of these changes for trading firms illustrate the advantage of being able to supply corn from multiple origins, as suggested in recent trade-strategy literature (Meersman,

[9] A trade story indicated that China preferred purchases from Ukraine due to Ukraine being less transparent than the United States with its export sale reporting (Polityuk and Hogan, 2021). Specifically, Chinese purchases during October 2021 were made from Ukraine instead of the United States, even though the latter had a lower cost. Upon further investigation, this allegation was more complicated and involved sales to public versus private firms as well as the availability of quotas for purchases from the United States (personal communication).

Reichtsteiner, and Sharp, 2012); the value of "switching options" was quantified by Johansen and Wilson (2019) and supported in recent texts about international grain trade (Kingsman, 2019; Blas and Farchy, 2021). Further, as exports grow, there would be a greater frequency for the supply capacity to be restricted. As a result, there is significant pressure on countries/firms for expanded logistics capacity. Indeed, expansion initiatives have been announced in the US Gulf, Brazil, and Ukraine.

This paper has several contributions. First, it uses the OMCS model, a novel technique for logistical analysis that has numerous prospective applications in agricultural marketing and risk research. Second, we specify supply-capacity restrictions to capture logistical constraints, which allows us to identify the likelihood of the logistical system being constrained. Third, the research contributes to understanding the logistical competitiveness of the global corn market with detailed data on transportation—including basis, secondary railcar values, port-elevation costs in the United States and Ukraine, and port basis values and ocean rates—that comprise the total delivered cost to the dominant destinations. These results should be interpreted as short-run findings. Certainly, over time (likely a longer time), there will be more adjustments, yet to be determined, that would influence the longer-run equilibrium effects of the invasion.

[First submitted August 2022; accepted for publication July 2023.]

References

AgriCensus. 2021. "Fastmarkets AgriCensus." Available online at https://www.agricensus.com/.

Ahn, S., D. Kim, and S. Steinbach. 2023. "The Impact of the Russian Invasion of Ukraine on Grain and Oilseed Trade." *Agribusiness* 39(1):291–299. doi: 10.1002/agr.21794.

Blas, J., and J. Farchy. 2021. *The World for Sale: Money, Power, and the Traders Who Barter the Earth's Resources*. New York, NY: Oxford University Press.

Bullock, D. W., P. Lakkakula, and W. W. Wilson. 2023. "Russia-Ukraine Conflict and the Global Food Grain Price Analysis." *Choices* 38(2):47–55. doi: 10.22004/ag.econ.338214.

Bullock, D. W., and W. W. Wilson. 2020. "Factors Influencing the Gulf and Pacific Northwest Soybean Export Basis: An Exploratory Statistical Analysis." *Journal of Agricultural and Resource Economics* 45(2):317–334. doi: 10.22004/ag.econ.302457.

Burlington Northern & Santa Fe Railway. "BNSF Railway." Available online at https://www.bnsf.com/.

CFTS Consulting. 2014. *Ukraine—Agricultural Trade, Transport, and Logistic Advisory Services Activity*. Kyiv, Ukraine: Centre for Transport Strategies. Available online at https://mtu.gov.ua/files/for_investors/Ukraine Agricultural Trade Transport and Logistic.pdf.

Data Transmission Network. 2023. "ProphetX." v4.11.1.6. Available online at https://www.dtn.com/financial-analytics/prophetx-download/.

Day, C. 2021, July 27. "Historic Land Reform Implemented in Ukraine." *U.S.-Ukraine Foundation*. Available online at https://web.archive.org/web/20210729184240/https://usukraine.org/content/historic-land-reform-implemented-in-ukraine/.

Eurasia Group. 2022, May 23. "Food Security and the Coming Storm." Available online at https://www.eurasiagroup.net/live-post/food-security.

European Commission. 2007. *Commission Regulation (EC) No 583/2007 of 29 May 2007 Amending Regulation (EC) No 1839/95 as Regards the Booking of Imports of Maize and Sorghum and the Communications to Be Made by the Member States Concerned*. 583/2007. Available online at https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:138:0007:0009:EN:PDF.

———. 2022. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: An Action Plan for EU-Ukraine Solidarity Lanes to Facilitate Ukraine's Agricultural Export and Bilateral Trade with the EU*. COM/2022/217 final. Brussels, Belgium: European Commission. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0217.

European Union. 2022. "Statistics." Available online at https://policy.trade.ec.europa.eu/analysis-and-assessment/statistics_en.

Figueira, G., and B. Almada-Lobo. 2014. "Hybrid Simulation–Optimization Methods: A Taxonomy and Discussion." *Simulation Modelling Practice and Theory* 46:118–134. doi: 10.1016/j.simpat.2014.03.007.

Glauber, J. 2023a. "The Impacts of the War In Ukraine on Global Markets—One Year Later." Presentation to the USDA Agricultural Outlook Forum. Available online at https://www.usda.gov/sites/default/files/documents/2023aof-Glauber.pdf.

———. 2023b, February 23. "Ukraine One Year Later: Impacts on Global Food Security." *IFPRI Blog*. Available online at https://www.ifpri.org/blog/ukraine-one-year-later-impacts-global-food-security.

Graubner, M., I. Ostapchuk, and T. Gagalyuk. 2021. "Agroholdings and Land Rental Markets: A Spatial Competition Perspective." *European Review of Agricultural Economics* 48(1):158–206. doi: 10.1093/eurrag/jbaa018.

Hall, B. 2023, March 18. "Ukrainian Black Sea Grain Export Deal Extended." *Financial Times*.

Hellenic Shipping News. 2022, June 16. "Consumers Heavy-Lifting Grains, Oilseeds Costs as Logistics Drive Up Prices." Available online at https://www.hellenicshippingnews.com/consumers-heavy-lifting-grains-oilseeds-costs-as-logistics-drive-up-prices/.

Informa Economics. 2018. *Impact on Crops and Product Export Flows of Dredging the Lower Mississippi River to 50 Feet*. Report prepared for the Soy Transportation Coalition. Informa Economics. Available online at https://www.soytransportation.org/newsroom/STCLowerMississippiRiver50-FootDraftStudy.pdf.

Interfax-Ukraine. 2022, June 30. "Tariffs for Passenger Rail Traffic Won't Increase—for Freight Will Rise." *Kyiv Post*.

Ivanova, P. 2023, April 14. "Best of: How Russia Loots Grain from Ukraine." *Financial Times*.

Ivanova, P., and R. Olearchyk. 2023, May 7. "Russia Starts Partial Evacuation from Southern Ukraine." *Financial Times*.

Johansen, S., and W. Wilson. 2019. "Valuing Switching Options in International Grain Marketing." *Agribusiness* 35(3):423–438. doi: 10.1002/agr.21593.

Kamrud, G., W. W. Wilson, and D. W. Bullock. 2023. "Logistics Competition between the U.S. and Brazil for Soybean Shipments to China: An Optimized Monte Carlo Simulations Approach." *Journal of Commodity Markets* 31:100290. doi: 10.1016/j.jcomm.2022.100290.

Kingsman, J. 2019. *The New Merchants of Grain: Out of the Shadows*. Self-Published.

Kullab, S. 2023, May 7. "Ukraine Farmers Surrounded by Risks, From Mines to Logistics." *Morning Ag Clips*. Available online at https://www.morningagclips.com/ukraine-farmers-risk-losing-their-lives-or-livelihoods/.

Lyddon, C. 2021, July 9. "Focus on Ukraine | World Grain." *World-Grain*. Available online at https://www.world-grain.com/articles/15532-focus-on-ukraine.

MacDonald, A., and T. Grove. 2022, June 19. "Ukraine's Farmers Start Harvest with Few Places to Store Grain." *Wall Street Journal*.

Mallory, M. L. 2021. "Impact of COVID-19 on Medium-Term Export Prospects for Soybeans, Corn, Beef, Pork, and Poultry." *Applied Economic Perspectives and Policy* 43(1):292–303. doi: 10.1002/aepp.13113.

Malsin, J., and A. Cullison. 2023, April 25. "Russia Renews Threats to Black Sea Grain Deal." *Wall Street Journal*.

Mano, A. 2023, February 8. “China Becomes Biggest Brazil Corn Buyer in January, Revised Trade Data Show.” *Reuters*.

McGrath, S., and B. Erling. 2023, March 29. “Ukraine Grain Glut Hits Agribusiness in Neighbouring Countries.” *Financial Times*.

Meade, B., E. Puricelli, W. D. McBride, C. Valdes, L. Hoffman, L. Foreman, and E. Dohlman. 2016. *Corn and Soybean Production Costs and Export Competitiveness in Argentina, Brazil, and the United States*. Economic Information Bulletin EIB-154. Washington, DC: USDA Economic Research Service. doi: 10.22004/ag.econ.262143.

Meersman, S., R. Reichtsteiner, and G. Sharp. 2012. “The Dawn of a New Order in Commodity Trading.” *Oliver Wyman Risk Journal* 2:1–9.

Nickel, R. 2023, March 1. “Insight: Soils of War: The Toxic Legacy for Ukraine’s Breadbasket.” *Reuters*.

Padilla, S., D. J. Ufer, S. Morgan, and N. Link. 2023. *U.S. Export Competitiveness in Select Crop Markets*. Economic Research Report ERR-313. Washington, DC: USDA Economic Research Service. doi: 10.22004/ag.econ.333553.

Palisade Corporation. 2023. “@Risk.” v8.3.2 [Build 42], Industrial Edition. Ithaca, NY: Palisade Corporation.

Pleasant, K. 2021, June 20. “Global Food Supply and Ukraine: The Soviet Union’s Breadbasket Plan to Feed the World.” *Pavlovsk*. Available online at https://web.archive.org/web/20210928105419/https://www.pavlovsk.org/global-food-supply-and-ukraine-the-soviet-unions-breadbasket-plan-to-feed-the-world/.

Polityuk, P. 2021, July 1. “Ukraine Launches Free Farmland Trade Despite Criticism.” *Reuters*.

Polityuk, P., and M. Hogan. 2021, November 15. “Chinese Buyers Bought Ukrainian Corn Last Week – Traders.” *Reuters*.

ProExporter Network. 2022. “ProExporter.” Available online at https://www.proexporter.com/.

Rathbone, J. P., and B. Hall. 2023, March 22. “Saving Ukraine’s Economy: The Grain Giant Fighting for Survival.” *Financial Times*.

Refinitiv. 2023, July 7. “Romanian Port Key for Ukraine Grain Faces Overflow as Black Sea Deal on Edge.” *Inside Commodities*. Available online at https://share.refinitiv.com/assets/newsletters/Inside_Commodities/IC_07072023.pdf.

Ren, H. 2021, April 12. “Higher Shipping Costs Are Here to Stay, Sparking Price Increases.” *Bloomberg*.

Reuters Staff. 2023, April 7. “Poland Halts Ukraine Grain Imports.” *Reuters*.

Sadden, E. 2021, October 13. “Dry Bulk Freight Rates Ease amid Heightened Volatility.” *Fastmarkets Agricensus*. Available online at https://www.agricensus.com/Article/Dry-bulk-freight-rates-ease-amid-heightened-volatility-18880.html.

Salin, D. 2020. “Ukraine Grain Transportation.” USDA 2020 Outlook Conference: Trade and Global Market Place.

Schade, B., and T. Wiesenthal. 2011. “Biofuels: A Model Based Assessment under Uncertainty Applying the Monte Carlo Method.” *Journal of Policy Modeling* 33(1):92–126. doi: 10.1016/j.jpolmod.2010.10.008.

Sizov, A. 2020. “The Black Sea: From the Largest Grain Importer to the Top World Exporter.” USDA 2020 Outlook Conference: Trade and Global Market Place.

Skadberg, K., W. W. Wilson, R. Larsen, and B. Dahl. 2015. “Spatial Competition, Arbitrage, and Risk in U.S. Soybeans.” *Journal of Agricultural and Resource Economics* 40(3):1–15. doi: 10.22004/ag.econ.210550.

Sorvino, C. 2023, February 12. “Despite Howard Buffett’s Help, Land Mines Litter Ukraine and Threaten Spring Planting.” *Forbes*. Section: Food & Drink.

S&P Global Platts. 2020, September 30. “Solving Corn: New Originations and COVID-19. Agricultural Special Report.” Available online at https://www.spglobal.com/commodityinsights/en/market-insights/special-reports/agriculture/corn-price-matrix.

Steinbach, S. 2023. "The Russia–Ukraine War and Global Trade Reallocations." *Economics Letters* 226:111075. doi: 10.1016/j.econlet.2023.111075.

Thukral, N., and G. Maguire. 2021, July 9. "Double Whammy for Food Buyers as Freight Costs Spike amid High Grain Prices." *Reuters*.

TR-Eikon. 2021. "Refinitiv Eikon." Available online at https://eikon.refinitiv.com/.

TradeWest Brokerage. 2013–2022. *PNW Secondary Rail Car*. Market Values January 2013–December 2022. Hillsboro, OR: Tradewest Brokerage.

UkrAgroConsult. 2022. *Black Sea Grain*. Weekly Market Report March 14-21. Kyiv, Ukraine: UkrAgroConsult. Available online at https://ukragroconsult.com/en/publication/market-report-black-sea-grain/.

United Nations. 2021. "UN Comtrade Database." Available online at https://comtrade.un.org/.

US Department of Agriculture. 2019–2021. "Ukraine Grain Transportation." Available online at https://www.ams.usda.gov/ services/transportation-analysis/ukraine.

———. 2022. *Global Agricultural Trade System (GATS)*. Washington, DC: USDA Foreign Agricultural Service. Available online at https://apps.fas.usda.gov/gats/default.aspx.

Van Trump Report. 2021, July 13. "More U.S. Competition: Land Market Reforms Giving Ukraine More Agricultural Potential." *Van Trump Report*. Available online at https://www.vantrump report.com/2021/07/13/more-u-s-competition-land-market-reforms-giving-ukraine-more-agricultural-potential/.

Verbyany, V., and A. DeSusa. 2021, June 20. "One of the Most Fertile Nations Wants to Feed the World: Ukraine Will Introduce Long-Awaited Land Reforms Next Month Just as Food Prices Rise to the Highest in Almost a Decade." *Bloomberg*.

Welsh, C. 2023. "The Impact of the War on Global Food Security." Presented at the 99th annual USDA Agricultural Outlook Forum, February 23. Available online at https://www.usda.gov/oce/ag-outlook-forum/2023-aof-program.

Wilson, W. 2020. "What Does It Take to Farm in Russia and Ukraine?" USDA 2020 Outlook Conference: Trade and Global Market Place.

Wilson, W., D. W. Bullock, and P. Lakkakula. 2020. *Dynamic Changes in Rail Shipping Mechanisms for Grain*. Agribusiness & Applied Economics Report 798. Fargo, ND: North Dakota State University. doi: 10.22004/ag.econ.303743.

Wilson, W., and P. Lakkakula. 2021. "Secondary Rail Car Values in Grain Transportation and Basis Values." *Agribusiness* 37(3):472–488. doi: 10.1002/agr.21677.

Wilson, W., P. Lakkakula, and D. W. Bullock. 2022. *Logistical Competition for Corn Shipments from the United States and Ukraine to Targeted International Market*. Agribusiness & Applied Economics Report 811. Fargo, ND: North Dakota State University. doi: 10.22004/ag.econ.319650.

———. 2023. *Implications of the Russian Invasion on the Logistical Competition for Corn Shipments from the United States and Ukraine*. Agribusiness & Applied Economics Report 820. Fargo, ND: North Dakota State University. doi: 10.22004/ag.econ.338529.

Worledge, T. 2023, April 6. "UN's AMIS Warns of 'Significant Challenge' ahead for Grain Corridor." *Fastmarkets Agricensus*. Available online at https://www.agricensus.com/Article/UN-s-AMIS-warns-of-significant-challenge-ahead-for-grain-corridor-28211.html.

Wright, R., I. Wright, O. Konovalova, and T. Booth. 2023, March 27. "Clearing Land Mines by Hand, Farmers in Ukraine Risk Their Lives for Planting Season." *CNN*. Available online at https://www.cnn.com/2023/03/27/europe/farmers-land-mines-clearance-ukraine-russia-invasion-intl-hnk/index.html.

Yale School of Public Health. 2022. "Ukraine's Crop Storage Infrastructure: Post Invasion Impact Assessment." Available online at https://hub.conflictobservatory.org/portal/home/item.html?id=281114778092459c90302901bb6698ae.