Agribusiness and Applied Economics Report No. 820 September 2023

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

William W. Wilson

David W. Bullock

Prithviraj Lakkakula

Department of Agribusiness and Applied Economics
Agricultural Experiment Station
North Dakota State University
Fargo, ND 58108-6050

Acknowledgements

The report was previously reviewed, and comments received from Kwame Addey, Frayne Olson and Sandro Steinbach.

This research was supported by Cooperative Agreement Number 20-TMTSD-ND-0004 with the U.S. Department of Agriculture, Agricultural Marketing Service. Author Contact(s): Email: william.wilson@ndsu.edu, Phone: 701-231-7472 USDA Contact: Delmy Salin, Email: Delmy.Salin@usda.gov Recommended Citation: Wilson, W.W., Lakkakula, P., & Bullock, D.W. (2021). Logistical Competition for Corn Shipments from the United States and Ukraine to Targeted International Markets. USDA Report https://ageconsearch.umn.edu/record/338529?ln=en. The findings and conclusions in this publication are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy. County commissions, North Dakota State University, and the U.S. Department of Agriculture cooperated.

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

Abstract The Russian invasion of Ukraine disrupted the grain flows from that region and worldwide. These changes are critical due to the war's influence on logistical costs, routes and capacities. As a result of the invasion, Ukraine has evolved from having some of the lowest logistical costs in the world to having the highest logistical cost. Logistics are critical for international competitiveness in commodities, and due to the invasion, these functions have been severely affected. Essential features for a logistical competition include internal logistical functions and costs, quality, port capacity and ocean shipping costs, each compounded by seasonal demands. This paper's purpose is to analyze the effects of the Russian invasion on the logistical functions and the costs for corn exports from Ukraine and its competitors using an optimized Monte Carlo simulation model. The findings indicate that before the invasion, Ukraine had logistical advantages for shipments to the European Union (EU) and was highly competitive in Indonesia and China; the United States had a logistical cost advantage over Ukraine to serve China, South Korea (from the U.S. Gulf) and Japan (from the Pacific Northwest (PNW)). The changes due to the invasion are substantial. Most important is the radical increase in shipping costs from Ukraine, reduced port capacity and export supplies. However, concurrent with the invasion were changes in some critical trade and marketing policies, thus influencing the international competition for corn.

Keywords: Russia invasion of Ukraine; logistics; corn; market shares; shipping costs, Black Sea grain trade, international competitiveness
JEL Codes: Q02; Q13

Table of Contents

List of Tables

List of Figures

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

1. INTRODUCTION

During the 2000's Ukraine emerged as a large and fast-growing corn exporter into markets that the United States traditionally dominated. In contrast, the United States was the dominant exporter of corn during the 1970s and 1980s, but its market share has declined. 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, firstly from Ukraine and, more recently (commencing fall 2022), from Brazil (Mano, 2023).

The invasion challenged the Ukrainian logistical system, thereby 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 (Sorvino, 2023; Wright et al., 2023; Kullab, 2023); nuclear-contaminated soils, potentially reducing yield for many years (Ivanova and Olearchvk, 2023; Nickel, 2023); trade controversy with Romania, Poland, and Hungary for depressing local cash prices (McGrath and Erling, 2023) and, by April, seeking to restrict grain flows from Ukraine to Poland but allowing grain through transit to Poland (Reuters, 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, the war's effect on export logistics was one of the most critical changes influencing export competitiveness.

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 "EU Solidarity Lanes" and the "Grain Corridor" was conceived in May 2022 (as originally described in European Commission, 2022) and was negotiated and implemented to facilitate shipping through selected ports around Odesa, primarily to poorer countries, commencing on July 14, 2022. The Black Sea Grain Initiative (simply referred as BSGI, or, 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, and in late April 2023 (Agricensus 2023), Russia threatened to end the Grain Corridor Agreement unless other concessions were provided (e.g., as discussed in Malsin and Cullison, 2023). In addition to the changes affecting logistical competition, there were near-concurrent changes in China's phytosanitary restrictions on corn imports from Brazil and the relaxation of the European Union's (EU) import tariffs. Finally, it is important that on July 17 2023, Russia suspended the Black Sea Grain Initiative and at the time of the writing of this report, the BSGI is not in effect.

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. The purpose of this study is to analyze the effects of the Russian invasion on the logistics of corn exports and trade from Ukraine and its competitors using an optimized Monte Carlo simulation model. Our focus is on corn flows from the major export ports to the major importing countries and regions as well as how changes in the logistical costs and functions, and the selected trade policies affect short-term, inter-country competition and commodity flows.

2. BACKGROUND AND PREVIOUS STUDIES

There are substantial institutional, trade and marketing practices that affect international competition for corn. This section reviews these topics.

2.1. 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. The costs for these functions are partially affected by each country's competitive, institutional and regulatory mechanisms, and taken together, they are the factors that affect the country's logistical advantage. For these reasons, analyzing the effect of logistical functions and costs and their effect on international competitiveness poses challenges to shippers and policies that affect logistics.

Over the past several decades, the United States grain marketing system has had notable changes in its logistics. These variations include an expanded export-handling capacity, the adoption of forward-shipping instruments (2nd railcar markets), shuttle rail shipping, and massive investments in the country's handling and rail infrastructure, all of which lower the marketing costs. These mechanisms are described elsewhere (Wilson, Bullock and Lakkakula, 2020; and Wilson and Lakkakula, 2021). Recent studies have shown that these mechanisms also affect export basis values (Bullock and Wilson, 2020; Wilson and Lakkakula, 2021). In addition, U.S. railroads use periodic “rail unload incentives” to make exports competitive in targeted transactions, and other studies illustrated the effects of these mechanisms on exports (Kamrud, Wilson and Bullock, 2022). The U.S. logistics system is heavily dominated by the river system which provides low-cost barge shipping. However, barge rates have substantial seasonality and volatility (intra-year and inter-year), and the river system needs upgrading (Informa Economics, 2018). Finally, U.S. growers have significant on-farm storage relative to competitor countries and relative to crop size.

Ukraine's agriculture (Lyddon, 2021; Pleasant, 2021) and its grain marketing systems are evolving (Salin, 2020; Sizov, 2020; Wilson, 2020). Over the past decade, there have been moderate increases with storage and country elevators, and extensive expansion for the export capacity. Interior rail-shipping costs were extremely low by international standards. 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 of private rail cars. The 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, under-utilized, and needs upgrades (CTS, 2014).

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

In addition to interior logistical costs export-market shares were affected by ocean shipping costs and differentials in the period following mid-2020 (Ren, 2021; Thukral and Maguire, 2021). Kamrud et al. (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 U.S. market shares the most.

2.2. Effects of the Russian Invasion on Export Logistical Costs from Ukraine:

There have been and continue to be numerous ramifications of the Russian invasion on Ukrainian agriculture. The logistical costs and functions changes are most important for the model developed in this paper. Ukraine has traditionally been a country with some of the lowest export-shipping costs in the world (Wilson, Lakkakula Bullock, 2021).

The effect of the invasion has increased prices to become among the highest cost in the world, and these changes are dramatic. UkrAgroConsult (2022) described new shipping routes and costs in addition to the extreme paucity of relevant data for analysis. There were increases for the interior and port elevation; higher rail and truck shipping costs; increased ocean rates, in general, relative to competing routes; and added costs related to the Grain Corridor, including war and commodity insurance, demurrage, delays, and inspection costs. Due to the closing of 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.

Traditionally, shipments were for rail to the Black Sea ports, including Odesa which was dominant. As a result of the invasion, other routes emerged. While multiple routes have been proposed and explored, the dominant route was for shipments on the Danube for exports through Constanta, and shipments through the western border for exports via Poland. (Figure 1) The route through Constanta was comprised of rail shipments to Danube area elevators, transfer to barge, and barge shipments to Constanta. Shipments through the Western Border involve rail to a shipping point in Poland, and elevator transfer to an alternative railroad (typically with a European gauge track). In the post-invasion period, the routes included reduced exports through Odesa and the Grain Corridor. The 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 via alternative routes are also greater.

Figure 1. Alternative Routes for Grain Shipments from Ukraine[1].
Source: Malsin and MacDonald, 2023.

To illustrate these effects, we developed details about the logistical routes and costs through discussions with Ukrainian trading firms and otherwise used publicly available data. Pre-invasion, the predominant origin was Odesa. During the post-invasion period, alternative routes were included (Table 1). Most important are shipments through Odesa, (inclusive of Odesa, Chornomorsk, Yuzhny/Pivdennyi) subject to the Grain Corridor provisions, and 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 for the alternative routes, including trucks and barges and handling. The pre-invasion costs from farm to FOB (free on

---

[1] Shares shown are for July 2022-July 2023, which differs from our study period.

[2] Nibulon, a major exporting company with export operations through Mykolaiv, indicated that pre-war “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; Kulab, 2023).

board) ship were $31/mt and increased to $70, $115 and $130/mt for shipments via Odesa, Constanta and rail through the western border, respectively. For comparison, competing U.S. origins during the same period were about $57 and $47/mt through the PNW and U.S. Gulf, respectively.[3]

Table 1. **Ukraine's Export Logistics Costs: Pre- and Post-Invasion ($/mt)**

	Pre-Invasion	**Post-Invasion**		
	Odesa	Odesa	Constanta	Rail Through Western Border
Basis to Grower				
Export Logistics Costs ($/mt)				
Interior Elevation	3	5	5	5
Rail to Odesa Rail to Izmail	20	35	40	
Rail to Border				40
Elevation			20	20
Rail				55
Barge			40	
Export Elevation	8	30	10	10
FOB Ship for Export	31	70	115	130
Added Grain Corridor Costs (War Insurance, Inspection, etc.)		27		
Total Logistical Costs	31	97	115	130
Export Capacity per Month (mmt/month)	7	3	3	1.5
Average Basis to Growers	+37	-90		

Source: Authors' calculations based on interviews with major Ukrainian grain traders.
The average basis to growers was derived as follows: pre-war (3rd qtr 2019-4th qtr 2021) vs. post-war (1st to 2nd qtr 2022), but, as low as -151 during 3rd qtr 2022. Authors' derivations using data from 2019-2021 https://www.ams.usda.gov/services/transportation-analysis/ukraine.

There are also capacity restrictions through these routes which were estimated to decrease from 7 mmt/month at Odesa pre-invasion to approximately 3, 3 and 1.5 mmt/month, respectively, for shipments via Odesa, Constanta, and rail through the western border. Added shipping costs through the Grain Corridor were approximately $27/mt due to war and grain insurance, demurrage, inspection costs and increased transit time. Finally, ocean shipping costs for shipments from the Black Sea to all

---

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

destinations increased relative to competing ports for numerous reasons. For example, the ocean rate from the Black Sea to Egypt was $12 over the U.S. Gulf rate in February 2022, and that differential increased to $34 in November 2022 (data from AgriCensus 2021b).

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 pre-invasion to $-90/mt in early 2022. These dramatic changes reflect a price decrease of $127/mt for growers, resulting in the net prices to growers being marginally less than production costs. The lower basis resulted in a smaller supply of corn for export. Other factors contributing to this diminished supply include reduced access to inputs, workers, etc. Estimates for the corn-export supply vary but generally decreased from 23.5 mmt in 2021 to 15 mmt projected for 2022/23; the current estimates (April 2023) for the 2023/24 exports range from 10-15 mmt.

2.3. Trade 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; VanTrump, 2021; Verbyany and DeSousa, 2021). However, substantial trade interventions affect competition in the global corn market and trade flows.[4] Key trade policies include China's tariff-rate quota (TRQ), the EU import restrictions for genetically engineered (GE) corn, the EU's 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 traditionally used phytosanitary regulations for its corn imports from Argentina and Brazil. These requirements must be met when trading corn to conform with the Chinese SPS restrictions. As a result, exports 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; the shipments commenced in November 2022 and has shipped more than 2 mmt of corn to China (as of June 2023)

2.4. Previous Studies: A few recent studies have analyzed the international corn market's logistics and spatial competition among corn exporters. Meade et al. (2016) examined the export competitiveness of corn (and soybeans) from Argentina, Brazil and the United States. The results indicated that the United States has an advantage with transportation costs, especially inland transportation costs, including 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 (2022) analyzed

---

[4] The trade-policy mechanisms which affect trade flows for corn are described, in detail, in Wilson, Lakkakula and Bullock (2021).

logistics competition for soybeans from interior U.S. and Brazilian origins to China, suggesting that there were natural equilibrium seasonal market shares, albeit 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 COVID-19 pandemic in the United States. This study illustrated the importance of logistical costs on export competitiveness. More recently, Padilla et al. (2023) studied U.S. competitiveness for corn and pointed to the importance of free trade agreements with corn. They also mentioned 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 Ukrainian invasion had major implications for commodity flows, trade routes and costs (UkrAgroConsult, 2022), grain storage (MacDonald and Grover, 2022) and food security (Eurasia Group, 2022). Recent studies assessed the broader changes in agriculture and trade. In addition, recent studies suggested the prospective changes in trade (e.g., Ahn, Kim and Steinbach, 2022; Steinbach, 2023); and papers presented at the International Agricultural Trade Research Consortium meeting [[IATRC Annual Meeting, 2022]). Bullock, Lakkakula and Wilson (2023) analyzed how the invasion impacted international prices and Glauber (2023a, 2023b) and Welsch (2023) described impacts of the invasion on food security.

3. RESULTS AND SENSITIVITY ANALYSIS

The model developed to analyze this problem is an Optimized Monte Carlo Simulation (OMCS) model and was used to derive optimal trade flows among origins and destinations under alternative scenarios, in this case pre- and post-invasion. This study focuses on the minimization of 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, and particularly relevant given the conflict.[5]

The model was simulated for both the pre-invasion and post-invasion periods.[6] 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 post-invasion period reflected the distribution for expected exports in 2023. The model determined the minimum-cost trade flows and should be considered to provide short-term values because 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 which are reported below. The results represent the logistical competitive advantage between specific origin-destination pairs.

---

[5] Details of the methodology, data and data distributions in Appendix A and B respectively.

[6] Pre and post were defined as the distributions derived from data in calendar year 2020 (all months) and for post-war, we used calendar year 2022 (all months).

The base-case scenario reflected the spatial competitive conditions and the market shares for major players in the global corn market during the pre-invasion period from 2015-February 2022. In addition to the highlighted constraints, restrictions were imposed for trade policies to reflect China's sanitary and phytosanitary standards and the EU's restrictions on genetically engineered corn imports from these origins. A constraint was not imposed on U.S. corn exports to the EU because of the *Abatimento* agreement with Spain and Portugal, through which most of the U.S. corn can be delivered to the EU (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 U.S. corn exports to the EU go to Spain and Portugal.

Figure 2 shows the probability distributions for the total cost from each origin port to China. (Similar distributions are derived for each month as well as pre- and post-invasion for each demand region/country.) These costs include the relevant basis and logistical costs described above. On average, Ukraine has the highest delivery costs, and Argentina is the lowest. The U.S. PNW has the lowest standard deviation, and the value for Ukraine, Brazil and Argentina is 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; in addition, the overlapping distributions explain 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.

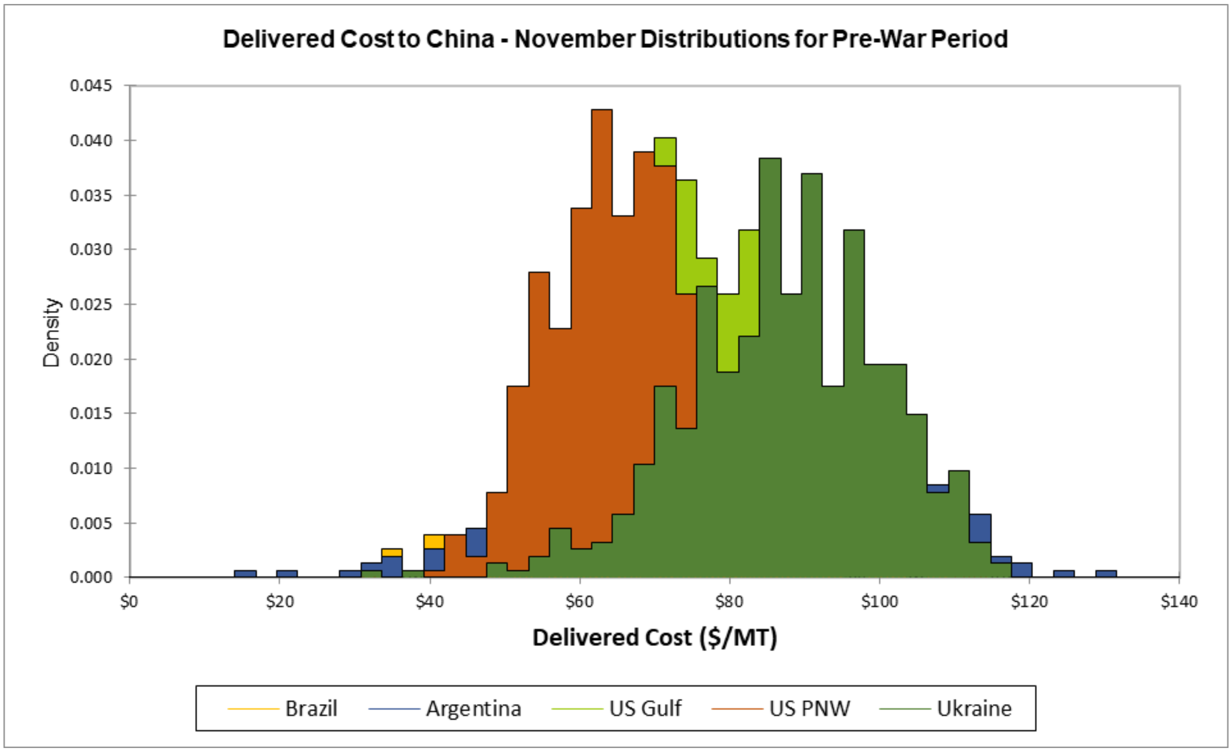

Figure 2. Probability Distribution of the Total Costs from Different Origins to China: Pre-Invasion for November.

3.1. Pre-Invasion: Results for the Least Cost Trade Flows: Table 2 shows the annual market shares of the trade flows for each origin-destination combination for the base case. The U.S. Gulf dominates the Chinese imports, the U.S. PNW dominates Japanese imports and Ukraine dominates the EU's imports. Brazil dominates the Middle East corn markets while Argentina dominates Vietnam, Indonesia and North Africa's markets. It is of interest that each destination imports corn from multiple exporters. The reasons for this result include 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). The second is that demand and some of the logistical costs are seasonal and would result in importers shifting among suppliers.

Table 2. Pre-Invasion Export Corn-Market Shares (% of Destination Imports)

Destination	**U.S. Gulf**	**U.S. PNW**	**U.S. Total**		**Ukraine**	**Brazil**	**Argentina**
China	47.3	35.4	82.7		15.8	0.8	0.7
Japan	7.8	29.3	37.1		8.1	19.7	35.1
Indonesia	7.6	7.6	15.2		20.9	24.0	40.0
The EU	14.2	0.0	14.2		68.7	15.2	1.9
South Korea	12.0	12.0	24.0		4.2	41.8	30.0
Vietnam	1.2	4.6	5.9		1.5	39.3	53.3
North Africa	14.4	0.0	14.4		5.8	1.0	78.9
Middle East	1.6	0.0	1.6		16.4	63.3	18.7
ROW	44.8	4.3	49.1		12.2	21.7	17.0
Prob Supply Constrained		.508			.475	.430	.328

The results can be interpreted as the likelihood that a specific flow is the lowest cost. The probability that the U.S. 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 U.S. PNW would be the least costly origin for Japan. Ukraine would, by far, be the least costly origin for the EU 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, diverts 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 U.S. PNW, which implies that the export capacity was hit in 50.8%of the iterations, and that the 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 U.S. PNW, Ukraine and Brazil.

3.2. Post-Invasion: Results for the Least Cost Trade Flows: During the post-invasion period, there were changes in logistical costs, routes and capacity; Odesa's ocean rates rose in addition to the Grain Corridor costs. Table 3 illustrates these effects and Figure 3 shows the changes in market shares, relative to the pre-war base case. Ukraine accrues losses to every market and region, due to the combined impacts of reduced exportable supplies, capacity constraints, and increased domestic and international logistical costs. This is offset by increased sales from rival exporters to most markets. The U.S. PNW gains volume in China. However, its share declines as capacity constraints keep it from achieving a higher share of Chinese market. It also loses share to other Far East markets as it has to reduce volumes to those markets to accommodate shift to China which creates opportunity for Argentina and Brazil to pick up share in those markets. The U.S. Gulf is the primary beneficiary of lost Ukraine share to China and the EU. The phytosanitary restrictions on Brazil's corn prevents Brazil from capitalizing on China. Port constraints become more prevalent in PNW and Ukraine.

Table 3. Post-War Destination Market Shares, excluding impacts of removing China's phytosanitary restrictions on Brazil corn) (% of Destination Imports)

Destination	U.S. Gulf	U.S. PNW	U.S. Total	Ukraine	Brazil	Argentina
China	53.4	32.1	85.5	12.8	0.8	0.9
Japan	5.1	24.9	30.0	2.5	19.9	47.7
Indonesia	4.7	3.1	7.8	14.3	25.5	52.4
The EU	21.4	0.0	21.4	61.0	15.6	2.0
South Korea	8.0	7.1	15.2	1.4	53.2	30.2
Vietnam	0.9	0.1	1.0	0.1	38.1	60.8
North Africa	4.3	0.0	4.3	0.7	1.8	93.1
Middle East	1.0	0.0	1.0	14.3	65.3	19.4
ROW	53.9	2.5	56.3	1.2	26.2	16.2
Prob Supply Constrained	.019	.697	.017	.889	.437	.463

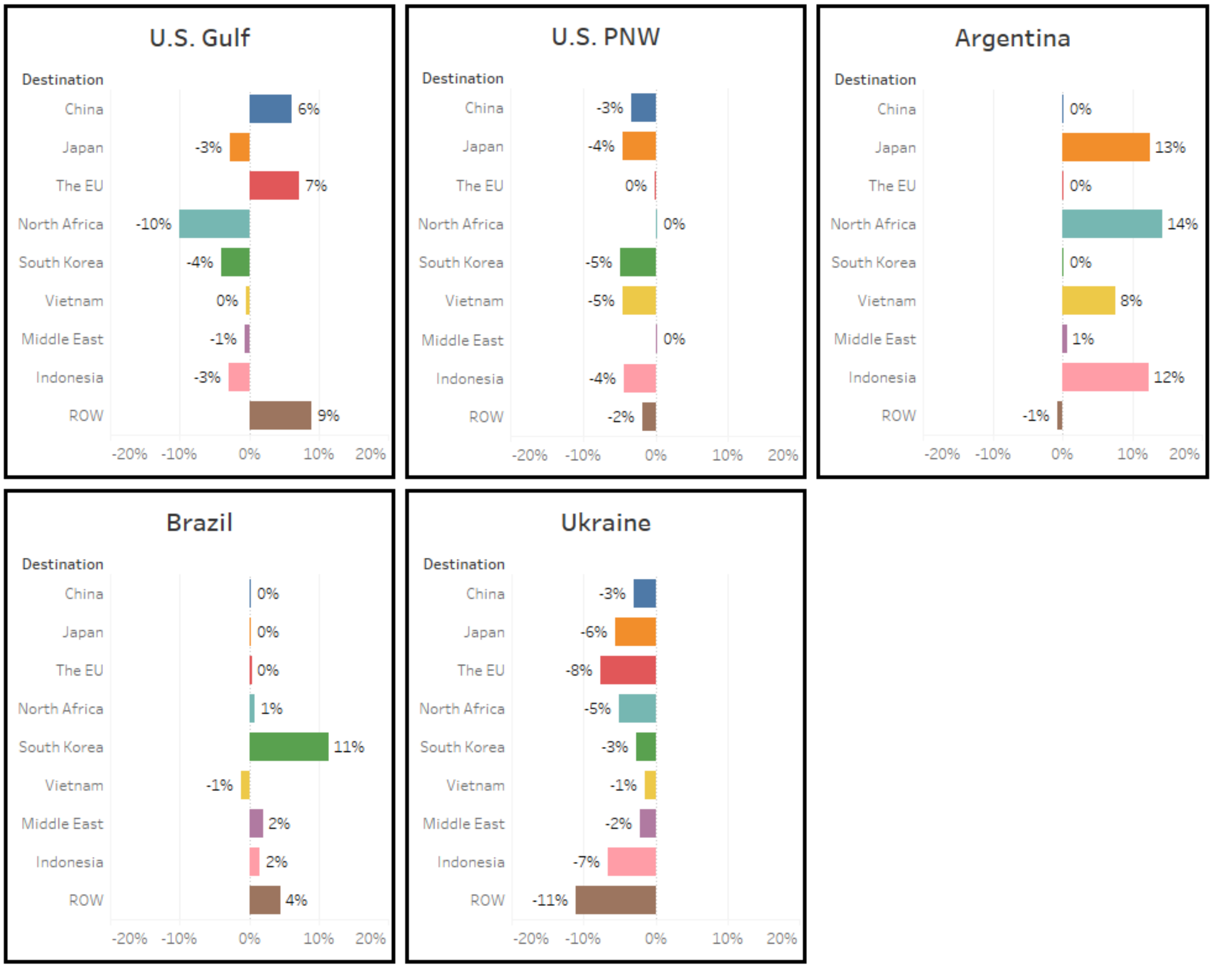

Figure 3. Post-Invasion Changes in Destination Market Shares, Excluding Impacts of Removing China's Phytosanitary Restrictions on Brazil Corn.

3.3. Post-Invasion: Sensitivities: Simulations were conducted under alternative assumptions to isolate the effects of specific variables. One of the most important changes was the relaxation of Brazil's phytosanitary restrictions on shipments to China. This change was concurrent with many other changes. To isolate the effect of this SPS policy, the post-invasion model was run with and without the restrictions. The results are shown in Table 4 and changes in market shares are shown in Figure 4. These effects were drastic. Brazil's market shares increased sharply, and the shares for the U.S. Gulf, the U.S. PNW, and Ukraine, fall. Other changes included reductions in Brazil's shipments to all other markets. Ukraine and Argentina increased shipments to the Middle East; the U.S. Gulf and the U.S. PNW had more shipments to South Korea; and Argentina sent more shipments to South Korea and Vietnam.

Brazil would be the lowest-cost supplier to China, with a probability of .679, and that value from Ukraine would be .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 only dominate Japan.

Table 4. Post-Invasion Export Corn-Market Shares (% of Destination Imports)

Destination	U.S. Gulf	U.S. PNW	U.S. Total	Ukraine	Brazil	Argentina
China	14.9	11.9	26.7	4.8	67.9	0.6
Japan	10.0	37.1	47.1	5.0	7.3	40.7
Indonesia	8.8	5.9	14.7	22.2	12.4	50.7
The EU	22.1	0.0	22.1	60.7	15.2	2.0
South Korea	15.8	13.0	28.8	3.4	31.5	36.3
Vietnam	1.8	0.1	1.9	0.1	25.8	72.2
North Africa	6.7	0.0	6.7	1.5	0.6	91.2
Middle East	1.9	0.0	1.9	26.2	43.4	28.6
ROW	63.2	4.7	67.9	2.2	14.6	15.4
Prob Supply Constrained	0.008	.550		.806	.602	.475

The percentage of simulation iterations that the supply capacity restriction is binding increased for all markets. The value for the U.S. PNW increases from 51 to 55 percent, and the values for Ukraine and Brazil increased from 47.5 to 81 percent and 43 to 60 percent, respectively. Argentina increased also from 33 to 47.5 percent. Thus, as a result of these changes, Ukraine's frequency of being at capacity has increased, as does that for Brazil. This result is due to the combined effects of Ukraine's reduced export supplies and the capacity constraints at the alternative export ports, including the Grain Corridor's influence. The increased value for Brazil is due, primarily, to the country's increased exports to China.

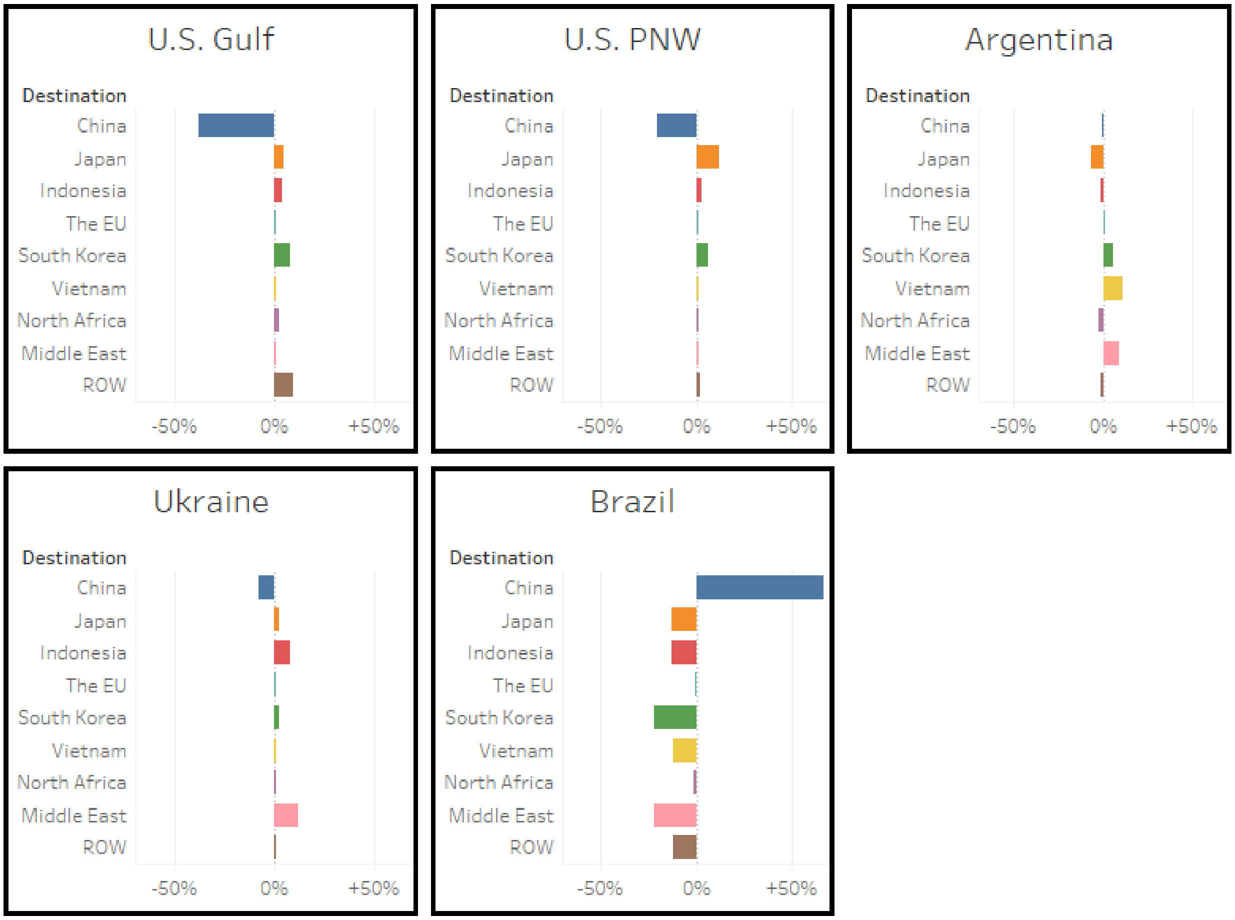

Figure 4. Changes in Destination Market Shares Due to Removing China's Phytosanitary Restrictions.

During the post-invasion 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 ocean shipping costs from each origin (Table 1). On average, the post-invasion distribution for Ukrainian shipments was mostly from Odesa and Constanta. The reason for this result is partly due to the reduced export supply and Poland having a slightly more significant ocean shipping cost. Without the corridor fee, Odesa was the dominant origin. With the corridor fee, some Odesa shipments to the EU 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 inspections-related costs; 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 EU decrease slightly. There are only minor adjustments for shipments from other origins.

Odesa plays a critical role with exports from Ukraine and for the world, partly because it was low-cost pre-war, and post-war, 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 zero (Table 5). Notably, if Odesa were closed, 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 almost all markets, except the EU, would decrease. Thus, operations at Odesa are critical.

Table 5. Change in Export-Market Shares: Restricting Total Odesa Exports to Zero (% Change in Destination Market Share)

Destination	U.S. Gulf	U.S. PNW	U.S. Total	Ukraine	Brazil	Argentina
China	0.9	0.9	1.9	–3.1	1.2	0.0
Japan	1.3	0.1	1.4	–3.6	0.1	2.2
Indonesia	2.5	1.1	3.6	–12.7	1.0	8.1
The EU	–0.4	0.0	–0.4	1.9	–1.5	0.0
South Korea	1.6	–0.6	1.1	–2.7	1.1	0.5
Vietnam	–0.1	–0.1	–0.2	–0.1	0.0	0.3
North Africa	–1.7	0.0	–1.7	3.4	–0.1	–1.5
Middle East	1.1	0.0	1.1	–20.7	10.6	9.0
ROW	–0.3	–0.3	–0.5	1.7	–0.6	–0.6

An important issue for the Grain Corridor 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. The dominant destinations during this period were actually to China and the EU (Spain and Turkey). This result is exactly what the post-war 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 EU but would shift its shipments to originate at Constanta, which is not part of the Grain Corridor.

Finally, we specified the post-war model to explore the potential effects if Ukraine were to return to normal. Specifically, we allowed Ukraine to have export supplies the same as with the pre-war scenario. All other changes for the trade policies and logistics remained at post-war levels. The results are shown in Table 6 and are drastic. Compared to the post-war base case, Ukrainian shipments increased to all destinations. There were notable increases to China, Japan, Indonesia, the EU, South Korea and the Middle East. In contrast, shipments were reduced from the U.S. Gulf, the U.S. PNW, and Brazil and Argentina.

Table 6. **Change in Export-Market Shares: Ukrainian Corn-Export Supply at Pre-War Levels (% Change in Destination Market Share)**

Destination	U.S. Gulf	U.S. PNW	U.S. Total	Ukraine	Brazil	Argentina
China	–5.2	–2.2	–7.3	10.4	–3.0	0.0
Japan	–3.8	–1.3	–5.1	9.9	–1.1	–3.6
Indonesia	–4.1	–1.2	–5.3	17.6	–3.4	–8.9
The EU	–9.9	0.0	–9.9	10.9	–0.9	–0.1
South Korea	–3.7	0.5	–3.2	8.8	–2.9	–2.7
Vietnam	0.2	0.1	0.3	0.6	0.7	–1.5
North Africa	–0.9	0.0	–0.9	6.0	–0.1	–5.0
Middle East	–1.6	0.0	–1.6	18.5	–9.9	–7.1
ROW	–6.1	–0.1	–6.2	7.3	–1.1	0.0

4. SUMMARY AND POLICY IMPLICATIONS

The purpose of this paper was to analyze the influence of logistical costs and functions on the United States' 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 was a short run and minimized the transportation and logistics costs subject to constraints. The problem was analyzed using an optimized Monte Carlo simulation 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 (as described in Appendix A & B respectively).

An important result was that, during the pre-invasion period, the United States had a logistical comparative advantage in serving China and Japan. The U.S. Gulf was the dominant port for export shipments to China, and the U.S. PNW had an advantage for shipments to Japan. Ukraine had a logistical comparative advantage for the EU. Brazil and Argentina had reduced market shares due in part to China's SPS policy. In the post-invasion period, the United States would only dominate Japan, and Ukraine would only dominate the EU. Brazil would dominate China and the Middle East, and Argentina would capture the dominant share of the other markets.

During the post-invasion period, there were changes in logistical costs, routes and capacity; Odesa's ocean rates rose in addition to the Grain Corridor costs. Ukraine accrues losses to every market and region, due to the combined impacts of reduced exportable supplies, capacity constraints, and increased domestic and international logistical costs. This is offset by increased sales from rival exporters to most markets. The U.S. PNW gains volume in China but its share declines as capacity constraints keep it from achieving a higher share of Chinese market. The U.S. Gulf is the primary beneficiary of lost Ukraine share to China and the EU. Port constraints become more prevalent in PNW and Ukraine.

Several changes occurred during the post-invasion period and are illustrated in these results. First, China's near-simultaneous approval of Brazil's corn phytosanitary procedures caused one of the most drastic changes in trade flows, diverting shipments from the U.S. Gulf and PNW and Ukraine to Brazil. Second, most of the post-invasion 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 suggest that that the EU would remain one of Ukraine's most advantageous destinations. 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 inferences could be drawn from this study. First, the findings indicated that the 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 U.S. Gulf and PNW should be the dominant origins for corn shipments to China, which differed somewhat from the observed shipments during the base period, where Ukraine was the dominant supplier. While there were many reasons for this distinction, important factors likely include 1) China's goal of diversification, 2) non-price preference for non-U.S. origin corn, and 3) the apparent non-transparency of Ukraine's export marketing.[7]

There are several trade implications from the Ukrainian invasion that could lead to long-lasting effects: 1) whether Ukraine's Odesa port reverts to its previous capacity and costs, 2) whether Ukraine's Odesa port re-opens, 3) the cost and capacity of alternative routes for Ukrainian grain, 4) the elevated shipping rates through alternative routes which has the impact of weakening Ukraine's basis and likely will impact production decisions, and 5) the capacity limits (constraints) for shipments through these routes and at those specific ports. The Grain Corridor has emerged to be 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 a natural trade flow is for Odesa shipments through the Grain Corridor to the EU post-invasion. This result has been a source of controversy with corridor negotiations because the intent was, in part, to facilitate trade 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 all origins as suggested in recent trade-strategy literature

---

[7] A trade story suggested 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. The authors suggested that China preferred Ukraine's corn because Ukraine was less transparent with sale reporting. Upon further investigation, this suggestion 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).

(Meersman, Reichtsteiner and Sharp, 2012); the value of ‘switching options’ were quantified by Johansen and Wilson (2018) and were supported in recent texts about international grain trade (Blas and Farchy, 2021; Kingsman, 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 capacity. Indeed, expansion initiatives have been announced in the U.S. Gulf, Brazil and Ukraine.

This paper has several contributions. First, it uses the OMCS model; this technique is novel for logistical analysis and has numerous prospective applications in agricultural marketing and risk research. Second, we specify supply-capacity restrictions to capture logistical constraints, which allows for identifying the likelihood of the logistical system being constrained. Third, the research contributes to understanding logistics of the global corn market’s logistical competitiveness with detailed data on transportation, including basis, secondary railcar values, port-elevation costs in the United States and Ukraine, as well as the 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, which would influence the longer-run equilibrium effects of the invasion.

REFERENCES

AgriCensus. 2021a. “Dry bulk freight rates ease amid heightened volatility.” Accessed October 13, 2021, from Agricensus.com.

AgriCensus. 2021b. “Fastmarkets AgriCensus.” Available at https://www.agricensus.com/

AgriCensus. 2023. UN’s AMIS warns of ‘significant challenge’ ahead for Grain Corridor, April 6, 2023.

Ahn, S., D. Kim, and S. Steinbach. 2022. The impact of the Russian invasion of Ukraine on grain and oilseed trade. *Agribusiness*, Volume 39, Issue 1. Winter 2023, pp. 291-299. https://doi.org/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*, Oxford University Press, 2021.

BNSF Railway. Available at hrrps://www.bnsf.com

Bullock, D. W., P. Lakkakula, and W. W. Wilson. 2023. *Russia-Ukraine Conflict and the Global Food Grain Price Analysis,* Choices, Vol 38 (2), pp. 1-9.

Bullock, D. and W. Wilson. 2020. “Factors Influencing Gulf and Pacific Northwest Soybean Export Basis: An Exploratory Statistical Analysis*, Journal of Agricultural and Resource Economics* 45(2):318–335

CTS. 2014. “Ukraine—Agricultural Trade, Transport, and Logistic Advisory Services Activity.” Center for Transport Strategies. Accessed from https://mtu.gov.ua/files/for_investors/Ukraine%20Agricultural%20Trade%20Transport%20and%20Logistic.pdf

Data Transmission Network. 2023. “ProphetX.” (Version 4.11.1.6).

Day, C. 2021. “Historic Land Reform Implemented in Ukraine, U.S. Ukraine Foundation.” Available at https://usukraine.org/content/historic-land-reform-implemented-in-ukraine/

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

European Commission. 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, May 12, 2022.

European Commission. 2007. “Commission Regulation (EC) No 583/2007”. Accessible at https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:138:0007:0009:EN:PDF

Fastmarkets. 2023. “AgriCensus.” Available online at www.agricensus.com.

Figueira, G., and B. Almada-Lobo. 2014. “Hybrid simulation–optimization methods: A taxonomy and discussion.” *Simulation Modelling Practice and Theory* 46:118-134.

Glauber, J. 2023a. “The Impacts of the War In Ukraine on Global Markets—One Year Later, ,” presentation to the USDA’s 99th annual Agricultural Outlook Forum 23 February 2023 Available at https://www.usda.gov/sites/default/files/documents/2023aof-Glauber.pdf

Glauber, J. 2023b. “Ukraine one year later: Impacts on global food security,” IFPRI Blog : Issue Post Feb 23, 2023 open access | cc-by-4.0 available 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.

Hall, B. 2023. “Ukrainian Black Sea grain export deal extended,” Financial *Times*, Mar 18, 2023.

Hellenic Shipping News. 2022. “Consumers heavy-lifting grains, oilseeds costs as logistics drive up prices,” in Commodity News 16/06/2022. Available at https://www.hellenicshippingnews.com/consumers-heavy-lifting-grains-oilseeds-costs-as-logistics-drive-up-prices/

IATRC Annual Meeting 2022. Turmoil in Global Food and Agricultural Markets: Implications of Russia’s Invasion of Ukraine, December 12, 2022.

Informa Economics. 2018. “Impact on Crops and Product Export Flows of Dredging the Lower Mississippi River to 50 Feet”. Accessible at https://www.soytransportation.org/newsroom/STCLowerMississippiRiver50-FootDraftStudy.pdf

Interfax-Ukraine. 2022. “Tariffs for passenger rail traffic won’t increase—for freight will rise.” Kiev Post: Ukraine’s Global Voice, June 30, 2022.

Ivanova, P. 2023. “Best of: How Russia Loots Grain from Ukraine,” *Financial Times*, podcast, April 11, 2023.

Ivanova, P. and R. Olearchvk, 2023. “Russia starts partial evacuation from southern Ukraine.” *Financial Times,* February 7, 2023.

Johansen, S., and W. Wilson. 2018. “Valuing switching options in international grain marketing,” *Agribusiness: An International Journal*, November 2018. Pp. 1-16.

Kamrud, Gwen, W. W. Wilson, D. W. Bullock. 2022. “Logistics Competition Between the U.S. and Brazil for Soybean Shipments to China: An Optimized Monte Carlo

Simulations Approach," *Journal of Commodity Markets*, ISSN2405-8513, https://doi.org/10.1016/j.jcomm.2022.100290

Kingsman, J. 2021. The Merchants of Grain: Out of the Shadows, 2021.

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

Lyddon, C. 2021. "Focus on Ukraine". *World Grain*. July 9.

MacDonald, A., and T. Grover. 2022. "Ukraine's Farmers Start Harvest with Few Places to Store Grain," *Wall Street Journal*, June 19, 2022. Available at https://www.wsj.com/articles/ukraines-farmers-start-harvest-with-few-places-to-store-grain-11655636400

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.

Malsin, J. and A. Cullison. 2023. "Russia Renews Threats to Black Sea Grain Deal Moscow accuses Ukraine of violating agreement with attacks in Crimea." *Wall Street Journal*, April 25, 2023.

Malsin, J. and A. MacDonald. 2023. "Great Power Rivalry Looms Over Ukraine Grain Deal: Russia's blockade of Ukraine grains threatens rift with China, Turkey," Wall Street Journal, July 28, 2023.

Mano, A. 2023. China becomes biggest Brazil corn buyer in January, revised trade data show. https://www.reuters.com/article/brazil-corn-china-idafl1n34o2b3

McGrath, S. and B. Erling. 2023. "Ukraine grain glut hits agribusiness in neighboring countries," Financial *Times*, March 23, 2023.

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." *USDA Economic Information Bulletin*, *154*. Accessed 08/01/2021 at https://www.ers.usda.gov/webdocs/publications/44087/59672_eib-154_errata.pdf?v=0

Meersman, S., R. Reichtsteiner, and G. Sharp. 2012. The dawn of a new order in commodity trading. *Risk Journal*.

Nickel, R. 2023. INSIGHT-Soils of war: The toxic legacy for Ukraine's breadbasket - *Reuters News* 01-Mar-2023.

Padilla, Samantha, D. J. Ufer, S. Morgan, and N.Link. March 2023. U.S. Export Competitiveness in Select Crop Markets, ERR-313, U.S. Department of Agriculture, Economic Research Service.

Palisade Software. 2023. “@Risk: Advanced Risk Analysis for Microsoft Excel.” (Version 8.3.2 [Build 42] Industrial Edition). Ithaca, NY: Palisade Software, Inc.

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

Polityuk, P. 2021. “Ukraine Launches Free Farmland Trade Despite Criticism.” Accessed at https://www.reuters.com/article/ukraine-agriculture-land/ukraine-launches-free-farmland-trade-despite-criticism-idUSL5N2OD3WM

Polityuk, P., and M. Hogan. 2021. “Chinese Buyers Bought Ukrainian Corn Last Week – Traders.” Accessed at https://www.nasdaq.com/articles/chinese-buyers-bought-ukrainian-corn-last-week-traders-2021-11-15

ProFarmer. 2021. “Corn Pauses, Beans Correct.” ProFarmer.com, Vol. 49, No. 41

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

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

Ren, H. 2021. “Higher Shipping Costs Are Here to Stay, Sparking Price Increases.” Accessible at https://www.bloomberg.com/news/articles/2021-04-12/higher-shipping-costs-are-here-to-stay-sparking-price-increases

Reuters. 2023. “Poland Halts Ukraine Grain Imports.” April 9, 2023.

TR-Eikon. 2021. “Thomson Reuters: Refinitiv Eikon.” https://eikon.thomsonreuters.com/index.html

S&P Global Platts. 2020. “Solving Corn: New Originations and COVID-19,” Agricultural special report. September 20. Available at https://www.spglobal.com/commodityinsights/en/market-insights/special-reports/agriculture/corn-price-matrix

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

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.

Scheresky, G., W.W. Wilson, and D.W. Bullock. 2022. “Spatial and Logistical Competition for Shipments to China from the United States and Brazil.” No. 812, North Dakota State University, Department of Agribusiness and Applied Economics. Available at https://ageconsearch.umn.edu/record/320807.

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. Black Sea Grain Export Market Session.

Skadberg, K., 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):442–456.

Sorvino, C. 2023. "Despite Howard Buffett's Help, Land Mines Litter Ukraine and Threaten Spring Planting," Feb 12, 2023.

Steinbach, S. 2023. "The Russia–Ukraine war and global trade reallocations." *Economics Letters*, 226, May 2023, 111075, ISSN 0165-1765, https://doi.org/10.1016/j.econlet.2023.

Thukral, N., and G. Maguire. 2021. "Double Whammy for Food Buyers as Freight Costs Spike Amid High Grain Prices." Accessible at https://www.reuters.com/world/double-whammy-food-buyers-freight-costs-spike-amid-high-grain-prices-2021-07-09/

TradeWest Brokerage. Daily Market Report. *PNW Secondary Rail Car Market Values from January 2013 to December 2022.*

UkrAgroConsult. 2022. Black Sea Market Report Weekly, March 14-21, 2022.

UN-Comtrade. 2021. "UN Comtrade: International Trade Statistics Database"

USDA AMS. Grain Transport Report Datasets, selected issues, available at https://www.ams.usda.gov/services/transportation-analysis/gtr-datasets

USDA AMS. Grain Transport Report Datasets, 2019-2021 https://www.ams.usda.gov/services/transportation-analysis/ukraine.

USDA-FAS. 2022. "Global Agricultural Trade System, Foreign Agriculture Service." U.S. Department of Agriculture.

VanTrump. 2021. "More U.S. Competition: Land Market Reforms Giving Ukraine More Agricultural Potential".

Verbyany, V., and A. DeSousa. 2021. "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." Available at https://www.bloomberg.com/news/articles/2021-06-20/global-food-supply-ukraine-soviet-union-s-breadbasket-plan-to-feed-the-world

Welsh, C. 2023. "The Impact of the War on Global Food Security," presentation to the USDA's 99th annual Agricultural Outlook Forum 23 February 2023 available 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. Black Sea Grain Export Market Session.

Wilson, W. W., D. B. Bullock, and P. Lakkakula. 2020. “Dynamic Changes in Rail Shipping Mechanisms for Grain”. Agribusiness and Applied Economics Report No. 794. https://ageconsearch.umn.edu/record/303743

Wilson, W. and P. Lakkakula. 2021. Secondary Rail Car Values in Grain Transportation and Basis Values*, Agribusiness*, AGR-19-0103 Volume37, Issue3 https://doi.org/10.1002/agr.21677 Summer 2021

Wilson, W., P. Lakkakula, and D. W. Bullock. 2021. Logistical Competition for Corn Shipments from the United States and Ukraine to Targeted International Markets. Agribusiness and Applied Economics Report No. 811 October 2021 and published as GTR Highlight: USDA Research Compares U.S. and Ukrainian Logistics in Exporting Corn available at https://ageconsearch.umn.edu/record/319650

Wilson, W., P. Lakkakula, and D. W. Bullock. 2024. Implications of the Russian Invasion on the Logistical Competition for Corn Shipments from the United States and Ukraine, Journal of Agricultural and Resource Economics, *forthcoming.*

Wright, R., I. Watson, O. Konovalova. and T. Booth. 2023. “Clearing land mines by hand, farmers in Ukraine risk their lives for planting season.” CNN Mar 27, available 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: https://hub.conflictobservatory.org/portal/sharing/rest/content/items/67cc4b8ff2124d3bbd5b8ec2bdaece4f/data

APPENDIX A. EMPIRICAL FRAMEWORK

A.1. 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 which is in the spirit of other recent similar models (e.g., Skadberg, et al., 2015; Kamrud, Wilson and Bullock, 2022).

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 post-invasion. This study focuses on the minimization of 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, and 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 feature of our problem which are not naturally included in gravity models are supply restrictions, random and correlated costs, and shipping costs which are non-proportional with distance and the relationship varies across routes (as pointed out below).

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, 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 (2022).

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 then determines the optimized decision based upon the observed values.[8] 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).

---

[8] Model details are discussed in Figueira and Almada-Lobo (2014), where the techniques were referred to as *sequential simulation-optimization* (SSO) models. The OMCS was used previously by Kamrud, Wilson and Bullock. 2022. A detailed discussion of the data and steps used in the OMCS are available in Wilson, Lakkakula and Bullock (2021).

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, because the data is a 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 for the determination of plausible historical or projected future scenarios. In summary, the OMCS model is appropriate for three reasons: 1) it is based on deterministic optimization, 2) a large number of plausible scenarios and 3) 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.

A.2. Model Specification: A stochastic optimization model of corn flows from Ukraine and other major exporters to major importers was developed 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, as defined below, from each origin to each destination multiplied by the amount of corn that was shipped. CIF prices were calculated as the sum of random ocean shipping costs from the origin port to the export destination plus the derived free-on-board (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 Software, 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 follows:

$$
\begin{gathered}
\min_{q_{ij}} C = \sum_{i=1}^{11} \sum_{j=1}^{8} \tilde{c}_{ij} q_{ij}, \\
\textit{subject to:} \\
q_{ij} \geq 0, \\
\sum_{j=1}^{8} q_{ij} \leq \tilde{Q}_i \text{ for all } i = 1, \dots, 11 \text{ origins}, \\
\sum_{i=1}^{11} q_{ij} \geq \widetilde{D}_j \text{ for all } j = 1, \dots, 8 \text{ destinations.}
\end{gathered}
\tag{1}
$$

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_{ij}). 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 could 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 must 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 U.S. crops was 25% and was added to the simulated p_{ij} values from U.S. origins to the EU. 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 EU, a similar constraint, with a maximum share of 18% (of all flows to the EU) for Brazil and 2% for Argentina, was applied.

The origins included three interior locations for each U.S. export port (Gulf and PNW), one export origin in Ukraine pre-invasion and three routes post-invasion. There was one export port each for Brazil and Argentina. For all U.S. origins except for St. Louis, 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. The tilde (~) indicates that the variable is 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 excluded. 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 zero.

APPENDIX B. DATA SOURCES AND SIMULATION PROCEDURES

This study’s focus was on corn shipments from origins in the United States, Ukraine, Brazil and Argentina. The U.S. origins were in six interior regions, with three shipping to U.S. Gulf ports and three shipping to U.S. PNW ports. For the U.S. Gulf, the interior origins were Champaign, IL; Lincoln, NE; and St. Louis, MO. The PNW's 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 EU, South Korea, Vietnam, North Africa and the Middle East. To avoid cases with zero 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 1B. For the United States, the cost elements at each inland sub-origin 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 U.S. Gulf (via the associated interior origins) to the EU included an additional 25% tariff. Statistical procedures were utilized to determine the best distribution for each random variable in the Monte Carlo simulation.[9]

---

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

Table 1B. Variables and Data Sources

Variable	Source
U.S. interior basis, prices and futures price	Data Transmission Network, TR-Eikon (2023)
U.S. rail tariff and fuel service charge	Burlington Northern & Santa Fe Railway (BNSF)[a]; USDA-AMS (2021)
U.S. daily car values	TradeWest Brokerage Co[b]
U.S. barge rates and tariffs	USDA-AMS (2021)
U.S. and Ukraine's export elevation	Industry sources and represented as distributions
Ukraine farm prices and basis	USDA-AMS (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 FOB basis	AgriCensus (2021b)
Trade flows	UN-Comtrade (2021): Ukraine, Brazil, Argentina and the world. USDA-FAS (2022), USDA-AMS (2021) and Data Transmission Network ProphetX[c]: U.S. ports' (U.S. Gulf and U.S. PNW) export flows. The European Union[d]: Europa.eu

Sources: [a] https://www.bnsf.com/

[b] Private cash grain broker

[c] https://www.dtn.com/agriculture/agribusiness/dtn-prophetx/

[d] https://ec.europa.eu/trade/policy/eu-position-in-world-trade/statistics/

B.1. Simulation of U.S. Interior Logistics and Handling Costs: Data for 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.

Barge rates from St. Louis to New Orleans 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 (ANCOVA) regression model was fitted to the historical index data:

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

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 iid 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 zero and a standard deviation equal to the regression root mean squared error (RMSE) was used to simulate the residual error term ($\tilde{\varepsilon}_t$), and then, the simulated value ($\tilde{k}_t$) was derived from equation 3, given a particular chosen year and month.

A similar regression model was fitted to the rail tariff plus fuel surcharge ($r_{i,t}$) data for each U.S. rail origin, and 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:

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

A related procedure was utilized to simulate each residual error term ($\tilde{\varepsilon}_{i,t}$) by using a normal distribution with a mean of zero 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 U.S. interior elevation and handling costs (e_i), with the same holding true at the U.S. Gulf and the U.S. PNW. Therefore, expert opinions were solicited to provide the most likely values for the interior ($0.35 per bushel) and port ($6.69 per metric ton) values. A triangular distribution was used to simulate the uncertainty, with the mode set to the expert-opinion values and a min/max range set at 10% of the modal value.

B.2. Simulation of U.S. Interior and South American Basis Values: Historical basis values ($b_{i,t}$) were derived from historical interior spot-cash prices for U.S. 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:

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

where all of the variables are the same as 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 zero and a standard deviation equal to the regression RMSE, and equation 5 was used to simulate the corresponding basis value.

B.3. 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 pre-invasion 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) criterion in terms of recommending a single best-fitting distribution. Figure 1B illustrates the Probability-Probability (PP) plots for the three recommended distributions. The three distributions were combined to simulate the basis values using a discrete distribution with a 0.333 probability of each distribution providing the simulated value. The utilized distribution was uniform for the post-conflict period, with the minimum and maximum values provided by the two observations.

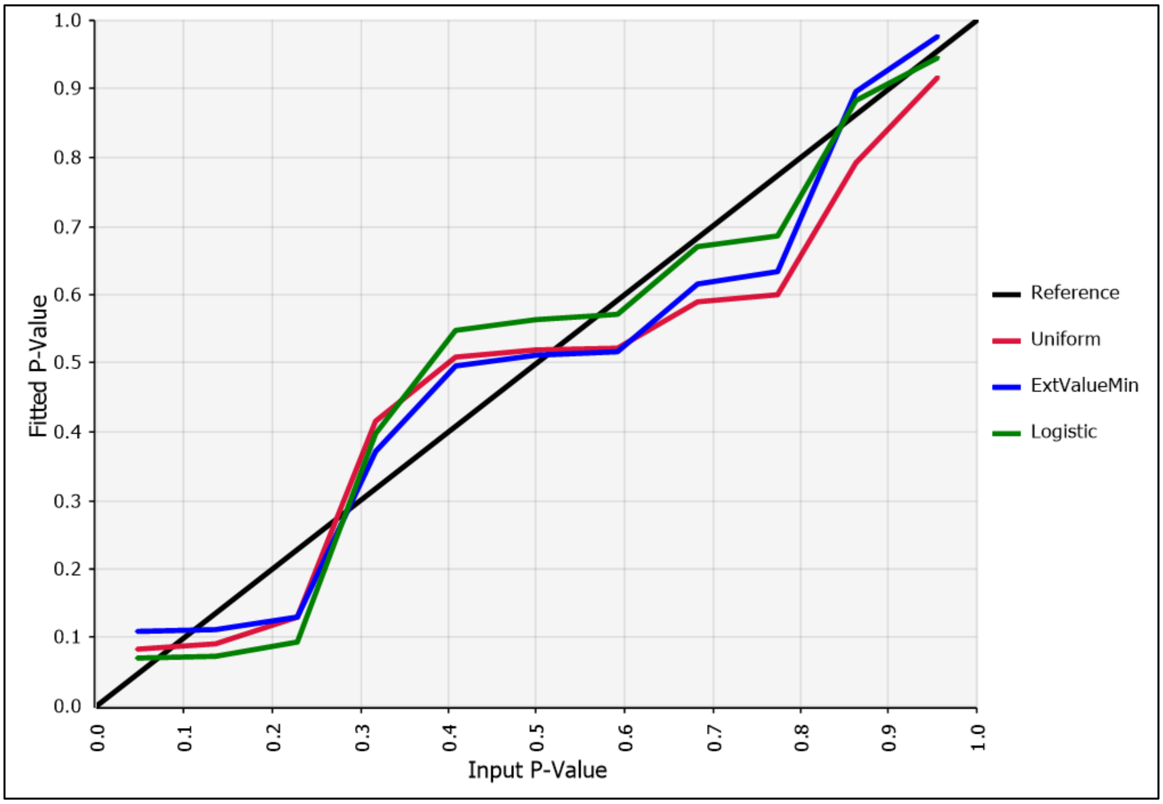

Figure 1B. Probability-Probability (PP) Plot of *Bestfit* Distributions for Ukraine's Pre-War Interior Basis (Central Region).

Data were developed from discussions with traders about Ukrainian logistical and handling costs and were then used to specify the most likely (modal) values. This information is summarized in Table 1 and discussed in a previous section. To account for uncertainty, triangular distributions, min/max range of plus/minus 10% of the modal values, were utilized to simulate the costs.

B.4. Simulation of the Ocean Shipping Rates: Monthly average ocean-shipping-rate (\$/mt) data were available for 30 routes. Partial (1 to 2 years) data were available for an additional 19 routes. Because there were no export flows from the U.S. PNW origin to the destinations of 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 per metric ton) to exclude these trade flows under all but the most extreme conditions.

Table B2 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 ocean-rate series:

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

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

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

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 zero 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 zero and a standard deviation equal to equation 6’s RMSE.

Table 2B. Spearman Rank-Order Correlation Matrix for Selected Ocean Rates, Brent Crude and Baltic Dry Freight Index

Variables	Brent	BDI	USGtoEU	PNWtoJPN	ARGtoCHINA	BRZtoEU	UKRtoCHINA
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**
USGtoEU	**0.6718**	**0.8298**	**1**	**0.8354**	**0.9613**	**0.9988**	**0.8522**
PNWtoJPN	**0.8024**	**0.6966**	**0.8354**	**1**	**0.8408**	**0.8420**	**0.7893**
ARGtoCHINA	**0.6563**	**0.8299**	**0.9613**	**0.8408**	**1**	**0.9626**	**0.8869**
BRZtoEU	**0.6835**	**0.8224**	**0.9988**	**0.8420**	**0.9626**	**1**	**0.8526**
UKRtoCHINA	**0.6293**	**0.7725**	**0.8522**	**0.7893**	**0.8869**	**0.8526**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

B.5. 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, constraining 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 diverted to alternative origins.

The supply-capacity constraints were derived for each export port (U.S. Gulf, U.S. PNW, Ukraine, Argentina and Brazil) by utilizing monthly total corn exports from January 2017 to December 2021. For the U.S. ports (Gulf and PNW), the simulated port capacities were allocated to the corresponding origin regions based upon historical production shares (using data from the Proexporter Network) for those regions during 2015/16 through 2020/21 marketing years. For the U.S. Gulf, the historical shares were 35.0% from Lincoln, NE; 10.3% from St. Louis, MO; and 54.7% from Champaign, IL. For the U.S. 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 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:

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

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 zero and a standard deviation equal to the regression RMSE, and then plugging it into equation 8.

B.6. 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.