WAR AND COMMODITIES

Investigating the impact of Russia's invasion of Ukraine on the wheat futures complex

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Applied Economics and Management

By

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May 2023

ABSTRACT

The current Russia-Ukraine war (2022-2023) poses challenges to wheat prices worldwide, and the price shock for the grain was a massive blow to countries that depend on wheat imports. This study aims to investigate how the effects of war including blockades, embargoes, and import quotas affect the welfare and price causality effects of regional and international wheat markets. We used time series futures data of Ukrainian wheat, Black Sea wheat, and CME wheat from May 2021 to February 2023 to analyze the changes in Granger causality measures of prices among wheat futures contracts traded on the Chicago Board of Trade (CBOT), including Ukrainian Wheat (KVH23) and Black Sea Wheat (FH23). We found that at the beginning of the war, around March 2022, there was a statistically significant temporal sequential prediction relationship between the three kinds of wheat under the influence of war. However, leading up to and following the start of the war, our vector autoregression (VAR) results indicated that historical Granger relationships were fractured. We conclude that the most enduring impact is the breakdown and realignment of historical trade relationships.

Keywords: Russia-Ukraine War, wheat futures, spatial equilibrium model, Granger Causality

BIOGRAPHICAL SKETCH

Wenhao Xu is a student at Cornell Dyson School of Applied Economics and Management, completing his master's degree from August 2021 to May 2023. Wenhao Xu concentrated on the management area in his graduate studies. His research interests align with supply and demand-induced price changes in commodity and futures markets, and he has taken various courses to further explore this area.

ACKNOWLEDGMENTS

Completing this thesis would not have been possible without Professor Calum Turvey's weekly meetings with me over the past year and his unfailing support to help me finish this thesis.

I am deeply grateful to Professor Calum Turvey and Professor Harry De Gorter for their encouragement and comments during the writing process, which helped me to revise and improve the whole thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. Introduction

This paper investigates the impacts of Russia's invasion of Ukraine on February 24th, 2022 and the ensuing war throughout 2022-2023 on the price of wheat. As Working (1941) indicates, war introduces a dynamic in domestic and global markets, but care must be taken to ensure greater causality. To this effect, I examine changes to Granger causality measures of prices among wheat futures contracts traded on the Chicago Board of Trade (CBOT), including Ukrainian Wheat (KVH23), Black Sea Wheat (KFH23), and CME Wheat (ZWH23). Over the past decades, Ukraine has become one of the world's leading grain exporters, accounting for 9% of global wheat exports in 2019. According to the Observatory of Economic Complexity (OEC), Russia and Ukraine exported about 25.4% of their wheat to the world in 2019, more than a quarter of the world's exports, and annual production volumes are continuing to grow to meet market demand. Russia initiated the war because it wanted to expand abroad to gain more resources, maintain public support, and increase its buffer zone with neighboring NATO countries. The Russian Navy blockaded Ukraine's Black Sea ports in the aftermath of the Russian-Ukrainian war. It seized over 20 million tons of grain intended for export, including wheat, corn, and sunflower oil, from multiple locations in Ukraine. Due to Ukraine's pivotal position among wheat exporters, global commodity and futures prices dramatically increased from February to mid-July 2022. The Black Sea Grain Initiative was signed by both sides on July 22, providing a safe corridor for shipping. According to the UN, the first ship sailed from Ukraine on August 1, and as of October 28, exporting more than 9.3 million tons of food through the Black Sea. Over the next three months, the FAO Food Price Index fell by about 15 percent as the highly volatile global wheat price leveled off. Government policies, including

tariffs, import quotas, and embargoes can significantly impact the cost of goods and simultaneously affect the consumer and producer surplus.

Previous research suggests that when tariffs, import quotas, increased transportation fees, or imposed embargo restrictions on multi-location transactions reduce producer and consumer welfare. In their studies, T. Takayama and G. G. Judge (1971) and Larry Martin (1981) provide spatial quadratic models for solving the transaction problems of interregional or international trade in agricultural products. Martin used a straightforward method to present a simple exposition of the quadratic programming model and extended the spatial quadratics models on the applications of the primal-dual formulation for multi-commodity problems. Also, our study relies on Holbrook Working's (1941) findings on the association between war and commodity prices. He provides guidance, such as that war should not be isolated as the sole factor in price changes. Ukraine and Russia are indeed the primary producers of wheat supplies, and their conflict led to a 17.1% YoY increase in March 2022 in grain prices, but the Russian port embargo against Ukraine was not the only reason for the increase in wheat prices. Concurrent events include but are not limited to, transportation difficulties due to the pandemic, rising freight costs, and intra-national embargoes triggered by various countries' concerns about regional supply shortages. According to the USDA, on May 19, 2022, India embargoed wheat and rice exports because of local temperature problems and concerns about domestic wheat shortages. War is a significant factor in commodity price volatility but should not be viewed as a sole factor. Pre-war economic conditions, including the Federal Reserve's quantitative easing in the pandemic, led to an inflationary environment in which the price of wheat futures had risen significantly in the six months before the war. Traditional economic factors such as rising energy and fertilizer prices will also affect wheat price volatility. In order to maintain a

balanced supply of wheat, output prices must rise. Russia is a major supplier of energy and fertilizer for wheat commodities. Its impact on price volatility is all-round, not limited to the war brought about by supply shortages and the direct impact of the embargo.

Working (1941) referred to the "absolute price theory" and the objections to the idea, saying that those who hold this idea believe that the concept of value is absolute and that comparing two periods of falling prices seems reasonable. They would argue whether a general change in prices was due to a change in the value of money or to a general change in the value of commodities. The starting point of the absolute value theory is that money has a value and prices are independent of the value of commodities, that each commodity also has a value, and that changes in the value of money are independent of changes in the value of commodities. The absolute value theory explains the price-setting process as a trade-off between the value of money and the value of commodities, which is an impractical theory. Values tend to be relative, not absolute, in a given situation. The price-setting process includes, but is not limited to, changes in monetary and commodity values, which explains why it is not feasible to consider changes in wheat futures prices in terms of a single factor, war. Considering where to export and where to import wheat is also an essential topic in the international wheat trade. How long a price shock lasts often depends on the ability to reallocate excess commodities to meet disruptions in export demand through the supply chain in regions with excess capacity. According to S&P Global Commodity Insights, Canada expects to harvest 33.8 million mt of wheat in the marketing year 2022-23 (August-July), 51.5% higher than the year before. (Sampad, 2022)[1] At the beginning of the Russian-Ukrainian war, Canadian and U.S. farmers

[1] Nandy, S., & Kaderabek-Vela, A. (2022, December 23). *Commodities 2023: Canada set to become a major wheat supplier in H1*. S&P Global Commodity Insights. Retrieved March 29, 2023, from https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/122322-Canada-set-to-become-major-wheat-supplier-in-h1-2023

anticipated a shortage of wheat supply and increased wheat acreage. They exported additional capacity to keep global wheat prices equilibrium. Wheat prices in other countries and international trade needed to be considered during the war, with wheat prices breaking new highs in the six months before the war to the first three months. The reasons for the price fluctuations included inflation caused by the currency increase during the pandemic, the blockade and embargo imposed by Russia on the Ukrainian port in Odesa, the difficulty in meeting the demand for wheat in the Middle East and Africa, and the ban on domestic exports of wheat in India. On July 22, 2022, Ukraine, Russia, Turkey, and the United Nations signed the Black Sea Grain Initiatives to ensure the safety of Ukraine's wartime wheat exports to avoid a global food crisis, and the U.S. Treasury Department announced that it would not impose sanctions on Russian grains and fertilizers. The agreement alleviated the global wheat trade situation. With the reallocation of wheat from countries such as the U.S. and Canada, wheat futures prices returned to pre-war levels.

1.1 Economic Problem

If the demand for the exported commodity is highly inelastic, even minor disruptions in trade can cause dramatic fluctuations in global prices. The demand for wheat, an essential food, will hardly decrease because of the price increase, and the war between Russia and Ukraine has gone far beyond minor disruptions, so it has a profound impact on the global price of wheat. European, American, and Asian countries grow, export, and reserve much wheat. The people of African countries have long depended on the wheat exported by Russia and Ukraine for their food rations, which is caused by the lack of substitutes and storage capacity. The Russian-Ukrainian war had a more direct impact on wheat prices in North African countries, with the New York Times reporting on July 22, 2022, that the disruption of grain exports from Ukraine

led to a spike in wheat prices of more than 60 percent in six months, exacerbating hunger and famine.

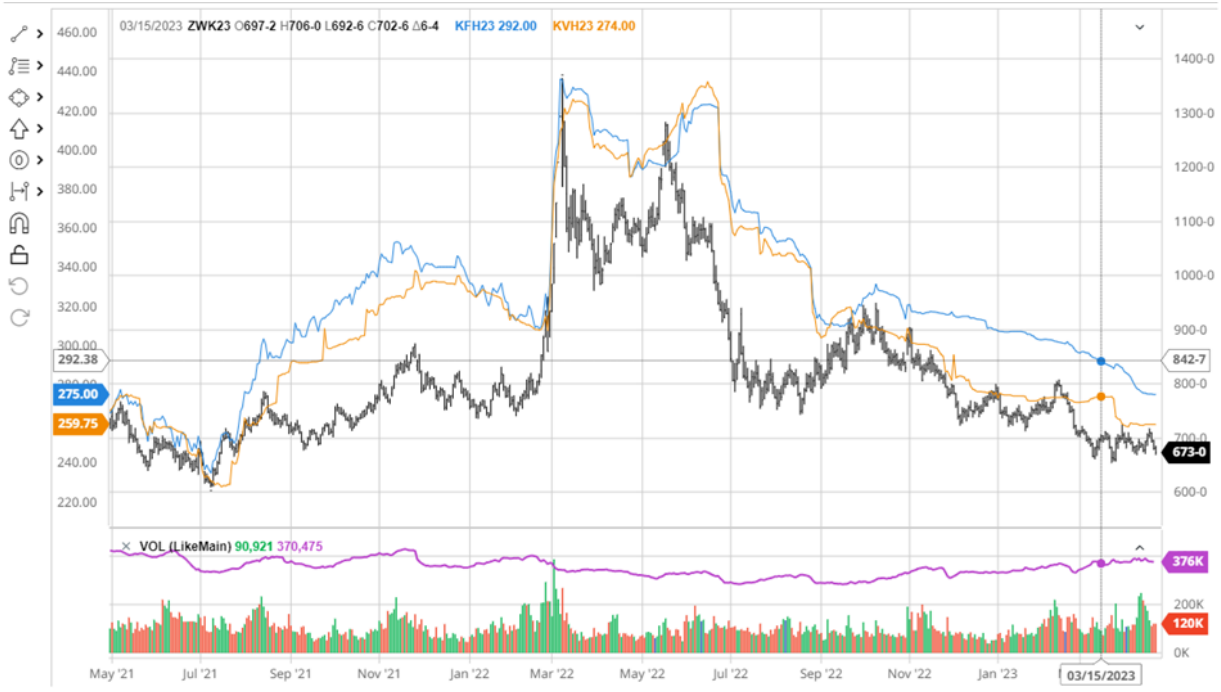

Figure 1: Ukrainian, Black Sea, and CME wheat future price changes 2021-2023

According to the Food and Agriculture Organization, the U.N.-brokered Black Sea Grain Initiative is significant for 14 African countries, which depend on the two belligerents for half of their wheat imports; one country, Eritrea, is entirely dependent on them. As Working says, war should not be considered the sole factor of commodity price increases. Nazanine Moshiri, an analyst with the International Crisis Group, says the agreement has had limited impact in some parts of Africa because those countries are struggling with internal political, economic, and social crises that have also led to hunger and an increase in wheat prices. (Dahir

& Peltier, 2022)[2] East African countries have suffered severe droughts within the last forty years that have decimated local farms and dried up rivers and wells. Civil wars in Ethiopia, political unrest in Sudan, and conflict and terrorism in Somalia have all contributed to regional food price uncertainty, making it difficult for governments and humanitarian agencies to assist.

The price shock of the Russia-Ukraine conflict is an external push for East African countries, but the reasons for high food prices are internal complications. In Kenya, rising government debt and inflation are driving up the prices of essential commodities, including wheat. The signing of the Black Sea Grain Initiative had a minimal impact on their wheat prices, and their local wheat prices have been unable to be eased after the Russia-Ukraine dispute. The Kenyan government's proposed solution is to reduce the taxes levied on imported grains and introduce government policies to reduce the retail cost of staple foods significantly. Changes in the value of commodities are not independent of changes in the value of money. (Dahir & Peltier, 2022) The observation aligns with Working's objection to the absolute value theory, where the price-setting process is relative. Depending on regional differences, government policies, including price controls, rationing of purchases, tariff embargoes, and blockades, are significant causes of wheat price changes.

This study aims to investigate how the effects of war and government policies such as blockades, embargoes and import quotas affect the welfare and price causality effects of regional and international consumers and producers. To accomplish the purpose of this study, we choose time series data of Ukrainian wheat, Black Sea wheat, and CME wheat from May 2021 to February 2023 to analyze whether there is a temporal Granger causality effect between

[2] Dahir, A. L., & Peltier, E. (2022, July 22). *'The deal should help us breathe': Africa welcomes Russia-Ukraine grain deal.* The New York Times. Retrieved March 30, 2023, from https://www.nytimes.com/2022/07/23/world/europe/the-deal-should-help-us-breathe-africa-welcomes-russia-ukraine-grain-deal.html

their prices. Three wheat futures are standardized contracts traded on the Chicago Board of Trade (CBOT), with Ukrainian and Black Sea wheat (Russian wheat) trading from 7:00 p.m. - 1:20 p.m. (Sun-Fri) CST and CME wheat trading from 7:00 p.m. - 7:45 a.m. and 8:30 a.m. - 1:20 p.m. (Settles 1:15 p.m.) (Sun-Fri) CST. (Settles 1:15 p.m.) (Sun-Fri) CST. The point value is $50, and the tick size is 0.25 points ($12.50 per contract). The contract size for Ukrainian and Black Sea wheat is 50 Metric Tons, while the contract size for CME wheat is 5000 bushels. To better compare the price causality of the three wheat futures contracts, our study unifies them into the CME wheat price of 5000 bushels per contract. By converting one metric ton = 36.7437 bushels of grain units, the costs of the three wheat futures were unified, which facilitated our study to analyze the time series data better.

1.2 Research Problem

Our paper investigates the cointegration of wheat futures prices between the Ukrainian, the Black Sea, and CME wheat. We narrow the scope of our study to focus on the daily nearest closing price. In our research, we are interested in how the war affected these futures. Under general assumptions of price discovery, we expect that correlation patterns prior to the war were disrupted by the war and events that arose following the original invasion. We, therefore, require vector-autoregression mode (VAR) to predict interconnected time series systems and to analyze the dynamic effects of stochastic perturbations on the method of variables. To reach this point in our study, we first had to do a smoothness test on the three wheat futures price variables. The original data were non-stationarity (i.e., there was a unit root) in the augmented Dickey-Fuller test. Then we obtained the first-order stationarity results after performing the first-order difference on the price variables in the unit root test.

The cointegration test indicates a stable relationship between two or more variables over time. The first-order stationarity of the unit root test provides a sufficient precondition for cointegration, which we obtained by cointegration test for a stable relationship between Ukrainian wheat, Black Sea wheat, and CME wheat over most of the period starting from May 2021 to mid-February 2023. Our study is divided into two parts to observe better the causal changes in the partial and full-time series. The first part of the time series is constructed for six months of data from May 2021 to October 2021. Then, the three wheat future prices data is extended by one month continuously until February 2023 (for example, June 2021 to November 2021, July 2021 to December 2021, ... September 2021 to February 2022… September 2022 to February 2023) to observe the marginal effect of increasing time series data on wheat prices causality at different times. In doing so we can monitor how the VAR changed as the potential for war approached as well as after the war was initiated. The fixed six months allow our study to observe the causal impact of war on the three wheat futures prices over a set time in the future.

Our study focused on the Granger causality test after the cointegration test; the Granger causality test is a test of the statistical temporal order of precedence. For example, If Black Sea wheat constitutes a Granger causality for Ukrainian wheat, we can use past Black Sea wheat prices to predict future Ukrainian wheat prices. According to the results of the Granger causality test, our study shows that the effect of war fractured the historical correlations and Granger effects between Ukrainian wheat, Black Sea wheat, and CME wheat. Temporal backward and forward explanatory relationships, became intensively de-linked and reordered in February and March 2022, when the war broke out, and lost almost all temporal stability between July 2022

and December 2022 due to the intensity of the war.

CHAPTER 2. Background to Russian-Ukrainian War

The beginning of the Russian-Ukrainian war dates back to February 20, 2014, with a sustained military standoff in a low-intensity manner after Russia captured the Crimea region in the early stages. It was not until February 24, 2022, that Russia invaded Ukraine under the slogan of demilitarization and de-Nazification that it gradually turned into a full-scale white-hot war. Russia has long claimed that they are conducting a special military operation rather than a total war, and Russian President Vladimir Putin had talked about preventing NATO from expanding its power in Ukraine and guaranteeing Ukraine's permanent neutrality. It is widely believed in the Western world that Russia's main reasons for the war included, but were not limited to, preventing NATO's eastward expansion, overthrowing the existing Ukrainian government, reducing gas pipelines subject to Ukrainian control, acquiring more resources, and expanding existing territory. Russia's most significant achievement has been the creation of a land bridge from the Russian border to the Crimea region and controlling the cities of Mariupol and Melitopol, turning the Sea of Azov into Russia's internal sea. From a BBC News report on February 24, 2023, mentioning the main objectives of Russia's war and the current results, the following chart shows how military control of Ukraine changed during the war. (Kirby, 2023) [3]

[3] Kirby, P. (2023, February 24). *Has putin's war failed and what does Russia want from Ukraine?* BBC News. Retrieved March 22, 2023 from https://www.bbc.com/news/world-europe-56720589

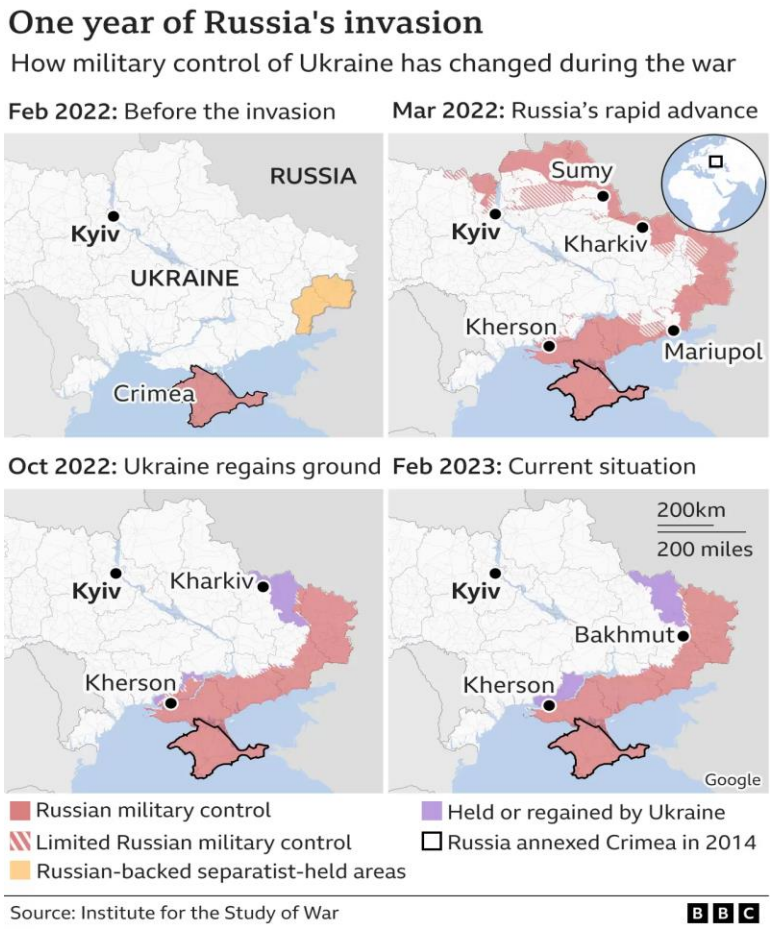

Figure 2: Military control of Ukraine changed after one year of Russia's invasion

The invasion extended Russia's territory and gave Russia a convenient and essential port for trade on the Black Sea. The WSJ reported on February 24, 2022, that commercial shipping to and from Ukraine had ceased mainly on the day of the military action, with ships prohibited from entering waterways and required to anchor if in port. The largest Ukrainian port in the Sea of Azov, Mariupol, and other ports on the Crimean Peninsula handle ships carrying exports such as corn, wheat, and barley to North Africa and Europe. (Paris & Benoit, 2022)[4] The sea is an

[4] Paris, C., & Benoit, B. (2022, February 26). *Ukraine closes Sea of Azov amid military action by Russia*. The Wall Street Journal. Retrieved April 10, 2023, from https://www.wsj.com/livecoverage/russia-ukraine-latest-news/card/ukraine-closes-sea-of-asov-amid-military-action-by-Russia-Sg4Q4idnoBwfzSAOZXsd

important transit route for Russian-produced oil destined for European markets. Russia and Ukraine account for nearly 30 percent of global wheat exports and 20 percent of corn exports. Wheat prices on the Chicago Mercantile Exchange rose highest over nine years, and European wheat futures climbed to record levels.

According to a BBC News report in March 2023, Russian troops moved quickly in the early stages of the war, taking control of much of Ukraine within a few weeks. They advanced to the outskirts of Kyiv and took control of most of the area around Sumy in northeastern Ukraine. Russian troops occupied territory as far as Kherson in the east and south and surrounded the port city of Mariupol. (T.V.J, 2023)[5] The rapid expansion of the Russian army's war order area in the early stage of the war was the time of the most dramatic price fluctuations for the three types of wheat in our research, as bombing and blockades significantly reduced Ukrainian wheat production and exports. However, they encountered stubborn resistance from the Ukrainian army in almost all areas and faced severe logistical problems, suffering from shortages of food, water, and ammunition. In July and August, the Ukrainian army rapidly deployed weapons from Western aid, and soldiers acquired adequate logistical support. The Ukrainian army reached its first turning point in the war when more arms aid arrived, and Russian troops withdrew from northern Ukraine in October after failing to take Kyiv. Our research identifies the signing of the Black Sea Grain Initiative and the withdrawal of Russian troops from northern Ukraine as important events at the height of the war. The war has predictably turned into a long, drawn-out war with mutual victories and defeats. The signing and renewal of the Black Sea Grain Initiative ensured that Ukrainian wheat had safe access to

[5] Team, T. V. J. (2023, March 9). *Ukraine in maps: Tracking the war with Russia*. BBC News. Retrieved April 10, 2023, from https://www.bbc.com/news/world-europe-60506682

sea transportation and that Black Sea wheat could export to countries needing wheat, including North Africa and Southeast Asia.

Russia's declaration of war on Ukraine and its latest trade policy have brought about significant export restrictions to Ukraine, which alone have caused wheat prices to rise by more than 20% in a short period, according to a World Bank report published on May 3, 2022. There is a link between the war effect and the increase in wheat prices, but not necessarily a causal one, as there are also effects such as raw material shortages and transportation disruptions. (Ruta, 2022). Russia's invasions have also been subject to sanctions by the U.S. and EU countries. The ban restricts companies and organizations directly or indirectly controlled by the Russian government from conducting export trade with foreign countries, including but not limited to natural gas, oil, agricultural products, and other types of resources. The number and size of the bans continue to grow. According to the WSJ, on February 26, 2023, the latest EU sanctioned a Russian oil trading company in the Middle East to reduce their energy revenues to Moscow. (Hirtenstein, 2023)[6] The move against offshore entities intended to prevent Russia from circumventing the sanctions to generate revenue, including Russia's wheat exports.

[6] Hirtenstein, A. (2023, February 26). *Sanctions net widens to catch Russia's Middle East Shipping Company*. The Wall Street Journal. Retrieved March 22, 2023, from https://www.wsj.com/articles/sanctions-net-widens-to-catch-russias-middle-east-oil-shipper-43938b0e

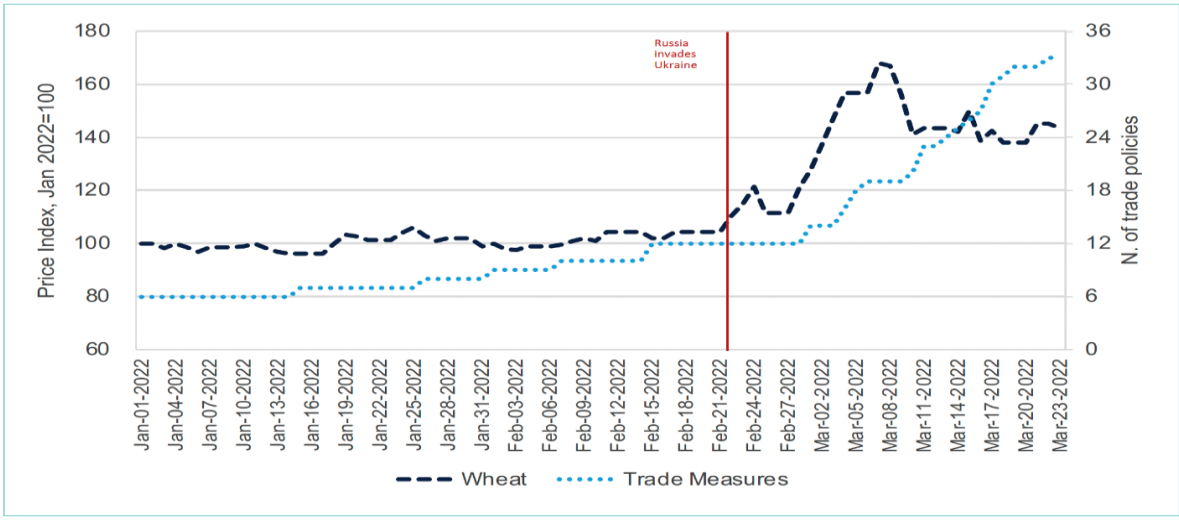

Figure 3: Wheat Price Index Jan 2022-Mar 2022

Our research aims to identify the link between war effects and trade policy changes on the price movements of Russian wheat, Ukrainian wheat, and CME wheat futures. Russia and Ukraine have a pivotal position in wheat export volumes, with Russia being the world's top wheat exporter, accounting for 23.92% of exports, according to 2018 FAO data. Ukraine ranks fifth in export volume, with 8.91% of exports. The two countries together account for more than one-third of global grain exports. Their direct military conflict has led to disruptions in the production supply chain and logistics of grain exports. Russia's further blockade of port vessels against Ukraine exacerbates the impact on global grain markets. With ports blocked, Ukrainian grain cannot safely be shipped out by ship. Land transport will not solve the enormous grain export problem, leaving an estimated 45 million tons of grain shortage on the international market. Russia is also the world's leading exporter of food and fertilizer, and the military conflict with Ukraine has affected the supply of agricultural products. An outright end to Russia's international trade could have a catastrophic impact on food market prices. In July 2022, the United States Treasury Department announced that it would not impose sanctions on Russian agricultural products, including fertilizers.

Meanwhile, the United Nations, Russia, Turkey, and Ukraine agreed on a Black Sea Grain Initiative for grain transportation from the Black Sea region, signed on July 22, 2022 allowing Ukraine to export grain from three ports for 120 days. The UN also signed a memorandum of understanding to ensure that Russian agricultural products, including fertilizers, will be returned to the international market. This agreement significantly eased the high prices of grains, including wheat, which were already near their peak in 2020 before the war and had risen by 235 percent compared to prices two years earlier when the war broke out in March. Wheat prices were 470.19 USD/bushel on March 17, 2020, and 11.16.3 USD/bushel on March 17, 2022. After the signing of the Black Sea Grain Initiative, the price came to a manageable 7.00 USD/bushel and has been lower since then. According to Barchart, on March 20, 2023, Russia agreed to extend the current agreement for at least sixty days. It promised to continue to provide grain and fertilizer exports to developing countries such as Africa even if a future agreement cannot be reached. (Hirtenstein, 2023)[7] The agreement has eased tensions in international grain and fertilizer markets over supply shortages in the past eight months, minimizing the impact of the war on grain prices after reopening ports such as Odessa. At the time of writing, most grain and fertilizer prices have returned to pre-conflict prices, but our research reveals how the embargo on Ukraine in the early stages of the war in March 2022 will impact wheat futures prices and how a later agreement could mitigate the price shock of the war.

[7] [7] Hirtenstein, A. (2023, February 26). *Sanctions net widens to catch Russia's Middle East Shipping Company*. The Wall Street Journal. Retrieved March 22, 2023, from https://www.wsj.com/articles/sanctions-net-widens-to-catch-russias-middle-east-oil-shipper-43938b0e

CHAPTER 3. The Economic Framework

Keeping in mind Working's (1941) commentary on commodities and war there is a need to anchor the economics in a general economic framework to examine significant economic impacts. These impacts include supply degradation to Ukraine, pillaging of stored commodities by Russia, and the effects of blockade and embargo. To accomplish this, we rely on Martin (1981) who provided a simple demonstration of the general equilibrium trade models in Takayama and Judge (1971). Because our interest is in general equilibrium welfare effects, we use the simple 3-region, single-commodity social welfare model with no modification to Martin's presentation. Coincidently the equilibrium prices in Martin are similar to the prices of wheat observed in the pre=war period before February 24th, 2022. The base model used assumes a simple demand and supply relationship as follows:

$$(1)\quad \begin{aligned} P_i^D &= \alpha_i - \beta_i y_i;\ i, j = 1 \to n, Y = demand \\ P_i^S &= \mu_i - \gamma_i x_i;\ i, j = 1 \to n, X = supply \end{aligned}$$

The general welfare function is developed by deducting the integral of demand from the integral of supply to capture changes in consumer and producer surplus after adjusting for transportation costs across trading regions. The regional quasi-welfare function is given by:

$$(2)\quad W(Y,X) = \sum_{i=1}^{n} w_i(y_i, x_i) = \sum_{i=1}^{n}\left(\alpha_i y_i - \frac{1}{2}\beta_i y_i^2 - \mu_i x_i - \frac{1}{2}\gamma_i x_i^2\right) - \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij} x_{ij}$$

and the base maximization problem is given by

$$(3)\quad Max(y,x,X) = \sum_{i=1}^{n}\left(\alpha_i y_i - \frac{1}{2}\beta_i y_i^2 - \mu_i x_i - \frac{1}{2}\gamma_i x_i^2\right) - \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij} x_{ij}$$

$$St$$

$$\sum_{j=1}^{n} x_{ij} \geq y_i, for\ all\ i,\ (no\ excess\ demand)$$

$$-\sum_{i=1}^{n} x_{ij} \leq x_i, for\ all\ i, (possibility\ of\ excess\ supply)$$

The Lagrangian for this problem and related Kuhn-Tucker conditions are given by:

(4) $$Max\phi\left(y,x,X,\lambda_y,\lambda_x\right)=\sum_{i=1}^{n}\left(\alpha_i y_i-\mu_i x_i-\frac{1}{2}\beta_i y_i^2-\frac{1}{2}\gamma_i x_i^2\right)-\sum_{i=1}^{n}\sum_{j=1}^{n}t_{ij}x_{ij}-\sum_{i=1}^{n}\lambda_y^i\left(y_i-\sum_{j=1}^{n}x_{ij}\right)+\sum_{i=1}^{n}\lambda_x^i\left(x_i+\sum_{i=1}^{n}x_{ij}\right)$$

$$\frac{\partial\phi}{\partial y_i}=\alpha_i-\beta_i y_i-\lambda_y^i\le 0 \;\; and \;\frac{\partial\phi}{\partial y_i}y_i=0$$

$$\frac{\partial\phi}{\partial x_i}=-\mu_i-\gamma_i x_i+\lambda_x^i\le 0 \;\; and \;\frac{\partial\phi}{\partial x_i}x_i=0$$

$$\frac{\partial\phi}{\partial x_{ij}}=-t_{ij}-\lambda_y^i+\lambda_x^i\le 0 \;\; and \;\frac{\partial\phi}{\partial x_{ij}}x_{ij}=0$$

$$\frac{\partial\phi}{\partial\lambda_y^i}=\left(\sum_{j=1}^{n}x_{ij}-y_i\right)\ge 0 \;\; and \;\frac{\partial\phi}{\partial\lambda_y^i}\lambda_y^i=0$$

$$\frac{\partial\phi}{\partial\lambda_x^i}=\left(\sum_{i=1}^{n}x_{ij}+x_i\right)\ge 0 \;\; and \;\frac{\partial\phi}{\partial\lambda_x^i}\lambda_x^i=0$$

$$x_i>0$$

$$\frac{\partial\phi}{\partial x_i}=0$$

$$\lambda_x^i=\mu_i+\gamma_i x_i$$

$$t_{ij}=\lambda_x^i-\lambda_y^i$$

The Kuhn-Tucker conditions provide interesting insights into the behavior of markets when faced with an economic shock. Assuming that there are no other hindrances to transshipments the constraint qualifications can be interpreted as follows.

1. If at the optimal solution $y_i>0$ then $\frac{\partial\phi}{\partial y_i}=0$, which implied that the optimal solution lies on the demand curve, and $\lambda_y^i=\alpha_i-\beta_i y_i$, that is the shadow price will equal the demand price. If $y_i=0$, then $\lambda_y^i\ge\alpha_i-\beta_i y_i$. Interpreting $\lambda_y^i\equiv P_y^i$, then the demand price could be higher than the equilibrium price.

2. Likewise, by interpreting the complementary slackness condition for supply, $\frac{\partial \phi}{\partial x_i} x_i = 0$ and λ_x^i as the optimal market supply price, then for $x_i > 0$, $\frac{\partial \phi}{\partial x_i} = 0$ and $\lambda_x^i = \mu_i + \gamma_i x_i$. Alternatively, if the complimentary slackness condition is not met, then $\lambda_x^i \leq \mu_i + \gamma_i x_i$. This may suggest that if in the short run, optimal supply conditions cannot be satisfied, then a disequilibrium in prices will result, thus causing a market distortion. This could involve more than a direct price effect and could also lead to price distortions across trading regions. For example, a blockade that restricts trade means that stocks are sitting idle (excess supply) with a shadow price approaching zero. This is the consequence of the blockade.
3. The third condition deals with trade flows, and if the complementary slackness condition is satisfied, it suggests that in equilibrium $t_{ij} = \lambda_x^i - \lambda_y^i$, which simply states that the price differential between two trading regions is the costs of transportation between the two. This wedge could be very important in war. With increased risks, costs of insurance, and fuel costs it would not be unusual for shipping costs to increase. This has the effect of increasing the price at the demand location, which in turn reduces import demand.
4. The last set of conditions deals with permissibility on excess demand and excess supply. Significantly, there can be no excess demand, meaning that demand across all regions must be satisfied along the demand curves, but there can be an excess supply. Practically, this means that any shortage in demand due to war and conflict will result in an increase in the demand price along the importing demand curve, while the possibility of excess supply will drive the shadow price (of the next unit of production) to zero.

We developed the model in Microsoft Excel using Solver's reduced gradient algorithm for a quadratic program. The matrix is illustrated in Figure 4.

Programming Tableau and Optimal Solution for Example Problem, Quantity Formulation																		RHS	
Decision Variables	y1	y2	y3	x1	x2	x3	x11	x12	x13	x21	x22	x23	x31	x32	x33				
	20	20	20	-5	-2.5	-5	0	-2	-2	-2	0	-2	-2	-1	0				
Objective Function	-0.05	0	0	0	0	0													
	0	-0.1	0	0	0	0													
	0	0	-0.0625	0	0	0													
	0	0	0	-0.05	0	0													
	0	0	0	0	-0.025	0													
	0	0	0	0	0	-0.05													
Constraints	-1						1			1			1			2.27E-07	≥	0	
		-1						1			1			1		0.124709	≥	0	
			-1						1			1			1	-7.5E-07	≥	0	
				1			-1	-1	-1							0	≥	0	
					1					-1	-1	-1				0.118702	≥	0	
						1							-1	-1	-1	0	≥	0	
constraint					1											125.2381	<=	80	1000
Shipments										1		1				25	<=	25	
Supply 1				1												57.619	=	57.619	
Supply 2					1											125.2381	=	125.2381	
Supply 3						1										47.61903	=	47.61903	

Figure 4: Image of programming tableau for spatial equilibrium model in Excel

To investigate the potential impacts of the war on wheat prices we add constraints to the base model. Base model results are found in Table 1, where region X2 represents the invaded supply nation (Ukraine) and the demand and supply volumes are provided without units of scale. Prices are deemed to represent $/bushel for wheat. In the base case region X1 produces 57.619 units and imports 34.76 units from Ukraine. Region 3 produces 47.62 units and imports 34.39 units from Ukraine to satisfy its demand. Ukraine produces 125.24 units of which 56.2 units are consumed domestically. Equilibrium prices for regions 1, 2, and 3 respectively are $10.76/bu., $8.76/bu, and $9.76/bu.

Table 1: General equilibrium base-case results

	Base Case			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	57.619	0.000	0.000	57.619

x2	34.762	56.190	34.286	125.238
x3	0.000	0.000	47.619	47.619
Demand (x)	92.381	56.190	81.905	0.000
Supply (Y)	57.619	125.238	47.619	
Demand price	10.762	8.762	9.762	
Supply price	10.762	8.762	9.762	

The first 'simulation' is to examine the effects of supply disruption. Ukraine supplies 125.238 units in the base case. Assuming varying degrees of supply interruption Table 2 provides 3 panels with supply restrictions to Ukraine of 100, 75, and 50 units.

Table 2: Effects of supply interruption on region X2 due to war

	R2 supply reduced from 125 to 100			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	63.489	0.000	0.000	63.489
x2	23.028	53.252	23.720	100.000
x3	0.000	0.000	53.493	53.493
Demand (x)	86.517	53.252	77.213	0.000
Supply (Y)	63.489	100.000	53.493	
Demand price	11.348	9.350	10.348	
Supply price	11.349	7.500	10.349	
	R2 supply reduced from 125 to 75			

Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	69.302	0.000	0.000	69.302
x2	11.395	50.349	13.256	75.000
x3	0.000	0.000	59.302	59.302
Demand (x)	80.698	50.349	72.558	0.000
Supply (Y)	69.302	75.000	59.302	
Demand price	11.930	9.930	10.930	
Supply price	11.930	6.250	10.930	

	R2 supply reduced from 125 to 50			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	75.007	0.000	0.000	75.007
x2	0.000	47.424	2.576	50.000
x3	0.000	0.000	65.234	65.234
Demand (x)	75.007	47.424	67.810	0.000
Supply (Y)	75.007	50.000	65.234	
Demand price	12.499	10.515	11.524	
Supply price	12.501	5.000	11.523	

The effects of supply restrictions to the exporting country are to increase equilibrium prices in importing nations while creating disequilibrium in the domestic (Ukrainian market). Due to reduced imports equilibrium prices in regions X1 and X3 increase from (10.762, 9.762)

to (11.348, 10.348), (11.930, 10.930), and (12.50, 11.52). Meanwhile, the original demand, the supply equilibrium price of Ukraine (8.762,8.762) is in disequilibrium with demand, supply pairs (9.35, 7.50), (9.93, 6.250), (10.515, 5.00). In other words, the effect of supply disruption on an invaded nation is to increase the price of wheat in its trading regions, increase the domestic demand price, and reduce the supply price. The reduction in the domestic supply price is due to supply becoming perfectly inelastic at the constraint point (100, 75, or 50) with the supply remainder considered to be unharvestable relative to the base case. In response, the importing regions increase supply to meet demand, but demand falls due to higher prices. The invaded nation continues to export but at new equilibrium levels of supply and demand.

These observations are consistent with Working's conjecture that it cannot be assumed that in times of war with supply disruption it is naïve to assume that the supply response of importing nations will not adjust. As global supplies fall, and export prices rise, there are economic incentives for trading partners to increase output. In terms of the Ukraine war, this is precisely what occurred. In the USA for example, farmers reduced corn acres and planted more to wheat as prices rose, and President Biden announced that land held in the 5th year of Conservation Reserve could be planted without penalty if the land was cultivated to wheat. Meanwhile, importing nations in the Middle East and Africa reduced import demand to avoid higher prices, reducing instead domestic stockpiles. As previously discussed, the global price of wheat rose rapidly following the invasion but fell throughout 2022 and into 2023 as global supply and demand forces adjusted to a new equilibrium. The immediate rise in wheat prices throughout March and April of 2022 was speculative in the sense that traders could not know immediately how global supply and demand would adjust to the war and reduced supply, but as trading nations adjusted supply and demand prices gravitated towards new equilibria.

Interestingly, towards the second half of 2022 and into 2023 Ukrainian futures prices fell below the Black Sea (Russian) futures price by a considerable margin which could be reflecting the impact of lower supply prices. However, the effect could also be due to the lifting of a Russian blockade at Odessa, as well as increased transportation costs. These are discussed next.

3.1 The Effect of Blockade

In addition to supply disruptions to agricultural regions, Russia took control of (and largely destroyed) ports at Mariupol and blockaded exports from Odesa. The blockade was lifted during the summer of 2022. Table 3 examines the effects of the blockade. In this model supplies were unconstrained but the trade flows from Ukraine to regions 1 and 2 were reduced. In the base case total exports to regions 1 and 2 were 69.048 units. The economics of the blockade are investigated for partial blockades of 50 and 25 units, and a total blockade of 9 units.

Table 3: Effects of partial and total blockade of exports by invading country

	Blockade (<50) to R1 and R3			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	61.222	0.000	0.000	61.222
x2	27.554	59.998	22.446	109.998
x3	0.000	0.000	54.199	54.199
Demand (x)	88.776	59.998	76.645	0.000

Supply (Y)	61.222	109.998	54.199	
Demand price	11.122	8.000	10.419	
Supply price	11.122	8.000	10.420	
	Blockade (<25) to R1 and R3			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	64.474	0.000	0.000	64.474
x2	21.053	65.000	3.947	90.000
x3	0.000	0.000	64.474	64.474
Demand (x)	85.526	65.000	68.421	0.000
Supply (Y)	64.474	90.000	64.474	
Demand price	11.447	7.000	11.447	
Supply price	11.447	7.000	11.447	
	Total Blockade (=0) to R1 and R3			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	75.000	0.000	0.000	75.000
x2	0.000	70.000	0.000	70.000
x3	0.000	0.000	66.665	66.665

Demand (x)	75.000	70.000	66.665	0.000
Supply (Y)	75.000	70.000	66.665	
Demand price	12.500	6.000	11.667	
Supply price	12.500	6.000	11.667	

As with supply disruption the effect of the blockade is to increase prices in importing countries, but new equilibriums of domestic prices fell to $8/bu, $7/bu. And $6/bu. As the blockade reduced exports, importing countries responded with increased production at higher marginal costs (supply prices). In response to higher prices, demand fell in importing countries. Domestically, the blockade increased supplies for domestic consumption forcing prices to fall. Domestic consumption of wheat rose with lower prices. Again, these effects are consistent with those observed. The reduced export supply price observed for Ukraine wheat after the blockade was lifted is more likely due to the lifting of the blockade and the resumption of exports in the Autumn of 2022. Although Russia had pilfered unknown quantities of Ukrainian wheat, there remained a substantial supply that was suddenly available on the world market. To move this wheat out of storage Ukraine faced a substantial excess export supply. This excess was due to built-up inventories to the blockade, as well as a reduced export demand due to higher world prices. As was observed in market prices, as the blockade was lifted, increased global supply saw a steady reduction in wheat prices throughout the second half of 2022, and into 2023.

3.2 The Effects of Increased Transportation Costs

In addition to supply constraints and blockade, Ukraine also faced higher transportation costs. Transportation costs rose as ocean freight had to spend more time in Black Sea ports due to the blockade and conditions of war. In addition, freight became uninsurable in the war zone

requiring shipping countries to self-insure by charging higher shipping costs. Table 4 provides optimal results for the base model with no blockade or supply constraints. Transportation costs doubled from $2/bu and then tripled to $6/bu to capture these effects. The results are provided in Table 4.

Table 4: Effects of rising transportation costs due to war

	Transportation costs from R2 are doubled			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	62.698	0.000	0.000	62.698
x2	24.603	63.651	7.143	95.397
x3	0.000	0.000	62.698	62.698
Demand (x)	87.302	63.651	69.841	0.000
Supply (Y)	62.698	95.397	62.698	
Demand price	11.270	7.270	11.270	
Supply price	11.270	7.270	11.270	
	Transportation costs from R2 are tripled to -6			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	72.222	0.000	0.000	72.222
x2	5.555	68.889	0.000	74.444
x3	0.000	0.000	66.665	66.665
Demand (x)	77.778	68.889	66.665	0.000

Supply (Y)	72.222	74.444	66.665	
Demand price	12.222	6.222	11.667	
Supply price	12.222	6.222	11.667	

Transportation costs are usually free-on-board (FOB) meaning that they are added by the shipper on top of the price at the export location. The effects of rising shipping costs are considerable. For importing countries, the prices rise as transportation costs are transferred to consumers. These costs cause a reduction in demand, which increases domestic supply in Ukraine. In essence, the port price in Ukraine must fall (to 7.27 and then 6.22). Even so, the costs are restrictive enough to encourage importing countries to increase domestic supply at higher supply prices. The spread between world prices as reflected in the new equilibria of the importing countries, and the lower equilibrium prices in the invaded countries is the more likely explanation for the widening spread between the Black Sea and Ukrainian wheat futures prices. The costs of transportation are thus borne by the consumers in importing countries and suppliers (farmers and warehouses) in the exporting countries. Importantly, even with Ukrainian resistance to Russia and the liberation of territories in the North and East, as well as the lifting of the blockade, the rising transportation costs are exogenous to domestic supply and demand conditions and remain in force regardless of how the war has progressed.

Finally, Table 5 explores the joint effect of a partial (50 unit) blockade and trebling of transportation costs. These results suggest that rising transportation costs can dominate the economic effects of the blockade on world prices. The joint effects cause higher domestic prices in importing countries and disequilibrium in the invaded country. The domestic price of the invaded country (Ukraine) is higher, but the export/supply price falls to $5/bu. The higher

domestic price is a consequence of the blockade reducing (in the long run) domestic production, with FOB supply prices still being forced to absorb the costs of transportation.

Table 5: Joint effects of rising transportation costs and partial blockade

	Blockade (<50) and Transportation costs from R2 are tripled to -6			
Trade Volume	TO			
From	x1	x2	x3	Supply (y)
x1	75.000	0.000	0.000	75.000
x2	0.000	50.000	0.000	50.000
x3	0.000	0.000	66.667	66.667
Demand (x)	75.000	50.000	66.667	0.000
Supply (Y)	75.000	50.000	66.667	
Demand price	12.500	10.000	11.667	
Supply price	12.500	5.000	11.667	

Although the above spatial equilibrium model is synthetic (following and using Martin, 1981 and Takayama and Judge), it provides the necessary anchoring and construction of an economic framework that is sympathetic to Working's (1941) caution against attributing observed market prices to war conditions alone. Global markets for commodities are integrated and it is unreasonable to presume under conditions of war that dynamic adjustments to equilibrium will not occur. This suggests that the effects of war should be examined through general equilibrium conditions of a spatial trade model. The effects of Russia's invasion of Ukraine and the effects of war on commodity prices are complex. However, examining the

effects of how war can affect domestic supplies, how the Russian blockade of Ukrainian wheat exports affected global markets, and the effects of higher transportation costs in the war zone provides the economic structure with which to examine commodity markets in wartime. The results of this section are consistent with observed market conditions affecting wheat prices leading up to the war and following the war.

The immediate effect was a rapid rise in wheat prices with the uncertainties of how the war would progress and whether the Ukrainian supply of wheat would be available in world markets. Anticipated supply reductions led to higher global prices. In the short run, the rise was substantial but as world conditions adjusted, new equilibria arose as global cultivation of wheat increased, and demand fell with higher prices. These adjustments led to more stable supplies in the intermediate term causing prices to fall. Coupled with ambiguous supply effects, Russia blockaded wheat (and other commodities) exports throughout the summer of 2022. The effect of the blockade, in isolation from supply effects, was substantial enough to increase global prices considerably while causing a decrease in domestic prices. However, even when the blockade was lifted, Ukrainian exports were subject to rising transportation costs due to a lack of insurance and increased risk to shippers and ocean freight. Although not definitive, it appears that since only Ukraine faced these higher transportation costs (within an unusually higher COVID-related supply chain effects), these costs are most likely the better explanation for why the price of Ukrainian sourced wheat was substantially lower than Russian Black Sea wheat throughout 2022 and 2023.

Chapter 4. Data

We focus on the futures prices of CME wheat, Black Sea wheat, and Ukrainian wheat, traded in the U.S. market. The data collected includes the last price of these three types of wheat on the CBOT exchange on a daily nearest basis. We note that the unit of trade for each contract is not the same, as the contract size for Black Sea wheat and Ukrainian wheat is 50 metric tons, while the contract size for CME wheat is 5000 metric tons. For the robustness of the future time series analysis, we unify the size of the three wheat contracts to 5000 bushels, for which we need to convert one metric ton to 36.7437 bushels of grain units to unify the contract size. All three types of wheat are traded in the U.S. market, and the prices are settled in U.S. dollars. In order to fully reflect the movements of CME wheat, Black Sea wheat, and Ukrainian wheat futures prices throughout the war, we have divided the historical wheat price data into pre-war, early-war, and post-Black Sea Grain Initiative in chronological order of occurrence. Each day has a corresponding time series of the three grains collected from Barchart, covering the period from May 3, 2021, to February 28, 2023. The period from May 3, 2021, to January 31, 2022, is the pre-war period; February 1, 2022, to July 29, 2022, is the beginning of the war; and August 1, 2022, to February 28, 2023, is after the signing of the Black Sea Grain Initiative. The exact war date is February 24, 2022, and the Black Sea Grain Initiative signing is July 22, 2022. Because our time series analysis compares price changes with Granger causality for the three wheat months versus the month before, we extend these three periods to the end of the month for accuracy.

There are 460 trading days in the entire time series data. Taking the CME wheat price as an example, the last price on a daily nearest basis on May 3, 2021, is $7.18/bushel, and the last price on February 28, 2023, is $7.055/bushel. The highest price occurred on May 17, 2022,

when it spiked to $12.775/bushel. After considering the other reasons mentioned in the introduction above, such as inflation, rising transportation costs, and other reasons that could affect the spike in wheat futures prices, we believe that war-induced disturbances and fear of uncertainty are the main reasons for the abnormal changes in wheat prices.

Our analysis employed vector autoregression (VAR) to better observe whether the pre-war prices of the three wheat futures affected the early-war and post-war periods and constituted Granger causality under the influence of war factors.

CHAPTER 5. Econometric framework with Vector Auto-regression (VAR)

The vector autoregressive (VAR) model relates the current observations of a variable to its past observations and other variables' past observations in the system. The VAR approach avoids the requirement of constructing the model by taking each endogenous variable as a function of the lagged values of all endogenous variables in the system. VAR models are effective forecasting models for systems of interconnected time series variables. In contrast, vector autoregressive models are frequently used to analyze the dynamic effects of different stochastic error terms on system variables. A VAR model is suitable if there is a lagged influence and a contemporaneous influence relationship between the variables. Its general form for 3 equations with p-lags is

1. $\gamma_{1,t} = \alpha_1 + \beta_{1,1} * \gamma_{1,t-1} + \beta_{1,2} * \gamma_{2,t-1} + \beta_{1,3} * \gamma_{3,t-1} + \varepsilon_{1,t}$

2. $\gamma_{2,t} = \alpha_2 + \beta_{2,1} * \gamma_{1,t-1} + \beta_{2,2} * \gamma_{2,t-1} + \beta_{2,3} * \gamma_{3,t-1} + \varepsilon_{2,t}$

3. $\gamma_{3,t} = \alpha_3 + \beta_{3,1} * \gamma_{1,t-1} + \beta_{3,2} * \gamma_{2,t-1} + \beta_{3,3} * \gamma_{3,t-1} + \varepsilon_{3,t}$

The above equation estimates each variable using the lag between itself and the other two variables. The variable α is a k vector of constants, and the variables of the formula y_{t-1}

indicate variable value one time period earlier. β_i is a time-invariant k*k matrix and ε serves as a k-vector error term. The error term satisfied the following assumptions that $E[\varepsilon_{i,t}]=0$, implying every error term has a mean of zero; $E[\varepsilon_{i,t}\varepsilon'_{i,t}]=\Omega$, the same period covariance matrix of error terms is a k × k matrix denoted Ω; $E[\varepsilon_{i,t}\varepsilon'_{i,t-k}]=0$, there is no serial correlation between each individual error terms. Our research focuses mainly on three-time series of wheat futures in CBOT: Ukrainian Wheat (KVH23), Black Sea Wheat (KFH23), and CME Wheat (ZWH23). The accuracy of most parameter estimates is insufficient when the sample size is too small, and VAR usually requires large samples. To be more precise with our results, we collect 460 trading days' last price on the daily-nearest basis for the analysis.

The augmented Dickey-Fuller test is a test for the stationary of the time series. The null hypothesis is that a unit root exists. Suppose we reject the null hypothesis, indicating that the data is stationary. In that case, we can further approach the Granger causality test to discuss whether there is a correlation between variables in different periods. If the data is not stationary, we need to do a cointegration test; otherwise, direct OLS regression will lead to the appearance of spurious regression. This means there is no causal relationship between the independent and dependent variables. However, due to the confounding factor or local stochastic trend, the regression analysis shows a statistically significant correlation between them, giving the false impression that there is a causal effect between them. When the data under test are non-stationary (i.e., there is a unit root) and the individual series cointegrated in the same order, an Engle-Granger test can determine whether there is a cointegration relationship between the variables, based on the regression residuals, which tested for the stationary of the residuals by building an OLS model.

Then we perform the Engle-Granger test within R to verify the long-term stationary relationship between two or more variables. As mentioned in the introduction, the first part of the time series is constructed for six months of data from May 2021 to October 2021. Then, the price data is increased by one month continuously until February 2023 to observe the marginal effect of increasing time series data on wheat prices causality at different times. The second part of the time series is six months of fixed time from May 2021 to October 2021, and moving forward, for example, the next period of data is from June 2021 to November 2021. The Engle-Granger test shows that in the first part of the time data, as the marginal effects are explored, the sample size of the time series data for each group doing the test increases, and the results will be more accurate.

The t-statistic values of the first part are all less than -2, which passes the E-G test and proves a long-term stationary relationship between multiple variables. The result of the E-G test is that all t-statistic values before the war were small enough to demonstrate a long-term relationship, but when the war broke out in February 2022 and the white-hot war after August 2022, this long-term relationship was disrupted, especially for the Ukrainian wheat with CME wheat, and Black Sea wheat with CME wheat. Their t-statistic values increased to the point that they failed the test and proved to be subject to spurious regression. The result might occur due to the war-induced embargo and increased transportation costs that isolated the correlation between local wheat and CME wheat. We will explain the results in detail in the VAR results section.

After passing the E-G test, we need to determine the lag order of the VAR to perform the Granger causality test. Intuitively, the choice of VAR lag order needs to consider the information criterion. We use Akaike's Information Criterion (AIC), Hannan- Quinn

Information (HQ), final prediction error (FPE), and Schwarz Criterion (SC) to determine, for example, if multiple information criteria choose second-order lags then we will choose second-order lags for Granger causality tests.

The Granger causality test is a statistical hypothesis test on whether the previous time series is valid for predicting another time series. The null hypothesis is that time series x does not constitute Granger causality between time series y. If the p-value obtained is significant, we can reject the null hypothesis and claim that they constitute Granger causality. We propose that the outbreak of war makes the time series of Black Sea wheat, Ukrainian wheat, and CME wheat, which initially had no or only partial Granger causality, become Granger causality with each other because the disturbance of the war makes them able to influence each other before and after time. The first part of the time series exploring the marginal effects supports our view that Granger causality between Ukrainian and Black Sea wheat arises from the beginning to the end of the war. In contrast, the original Granger causality between Black Sea wheat and Ukrainian wheat is disrupted. In the second part of the 6-month fixed time series, Granger causality appeared only briefly at the beginning of the war outbreak. Later, they became unpredictable from each other, and there was no long-term stationary relationship.

CHAPTER 6. Vector Auto Regression (VAR) Results

Table 6: Marginal effect of pre-war Granger causality

	5/2021-10/2021	5/2021-11/2021	5/2021-12/2021	5/2021-1/2022
(ukr,black)	0.0005765	0.0001454	0.00005921	0.00002338
(black,ukr)	0.5805	0.4115	0.2829	0.1732
(ukr,cme)	0.01168	0.0213	0.01052	0.01816
(cme,ukr)	0.3848	0.2717	0.1939	0.09874
(black,cme)	0.4375	0.1361	0.134	0.06768
(cme,black)	0.08551	0.04534	0.02396	0.01382

The VAR results in Table 6 capture the effect of each additional month in the pre-war period on the Granger causality p-value. For example, (UKR, black) refers to the validity of past Black Sea wheat prices for future Ukrainian wheat price forecasts. The "cause" of Granger's causality effect is in the second part of the parentheses. The coming numbers marked in red represent p-values with significance, and we can see that from May 2021 to January 2022, before the war, past Black Sea wheat prices have a long-term stationary Granger for Ukrainian wheat. In contrast, the price of Ukrainian wheat does not constitute a Granger causality for Black Sea wheat; however, due to the tensions between Russia and Ukraine before the outbreak of war, the fear of war has driven up the price of wheat, and the closer to February 2022, the smaller the p-value among Ukrainian wheat, Black Sea wheat and CME wheat to each other, indicating the emergence of a forecasting relationship of mutual price effects.

Table 7: Marginal effect of early war Granger causality

	5/2021-2/2022	5/2021-3/2022	5/2021-4/2022	5/2021-5/2022	5/2021-6/2022	5/2021-7/2022
(ukr,black)	0.0001815	0.05804	0.06482	0.1157	0.1828	0.2065
(black,ukr)	0.368	0.001609	0.0001941	0.0001239	0.0003823	0.0002412
(ukr,cme)	0.01144	0.05243	0.01403	0.01319	0.0004829	0.000386
(cme,ukr)	0.5451	0.0008037	0.02634	0.05199	0.0259	0.03212
(black,cme)	0.6494	0.1824	0.1709	0.2014	0.04265	0.02724
(cme,black)	0.5767	0.01063	0.09294	0.207	0.1916	0.1848

Table 7 shows the p-value of Granger causality after the outbreak of war, which was declared precisely on February 24, 2022, and directly disrupted the market price of wheat futures. The price of the CME wheat contract on February 18 was $8.04/bu, while the price on March 8 was 12.86/bu. In February, we speculate that the dramatic price fluctuations caused Ukrainian and Black Sea wheat to no longer have the Granger causality with CME wheat. However, Black Sea wheat still maintained its predicted relationship with the future prices of Ukrainian wheat. At the beginning of the Russian-Ukrainian war, Russia occupied important ports and imposed a seaborne blockade on Ukrainian wheat exports. Except for CME wheat, which does not constitute a Granger causality for Black Sea wheat, all five relationships emerge as price prediction relationships that affect each other due to the outbreak of war. This long-term stationary relationship is maintained as the war continues to advance. After May 2022, Russia was subject to trade sanctions. It gradually lost control of the area around the Ukrainian capital Kyiv and retreated to Kherson, and Ukraine received arms support and logistical assistance from the West. Black Sea wheat no longer constitutes a Granger causality between Ukrainian and CME wheat.

Table 8: Marginal effect of later war Granger causality

	5/2021-8/2022	5/2021-9/2022	5/2021-10/2022	5/2021-11/2022	5/2021-12/2022	5/2021-1/2023	5/2021-2/2023
(ukr,black)	0.128	0.1347	0.1651	0.2717	0.1376	0.1482	0.1466
(black,ukr)	0.000315	0.0002636	0.0001869	0.0001271	0.0001582	0.0001002	0.00006017
(ukr,cme)	0.0002026	0.0003135	0.0007804	0.002433	0.001055	0.0009047	0.0008634
(cme,ukr)	0.08413	0.08335	0.06358	0.02971	0.03057	0.02144	0.01657
(black,cme)	0.01896	0.01897	0.02376	0.0283	0.02258	0.01822	0.01545
(cme,black)	0.2605	0.2237	0.2196	0.1824	0.1536	0.1334	0.1252

On July 24, 2022, Ukraine, Russia, and the United Nations signed the Black Sea Grain Initiative to ensure a particular sea transport channel to help Ukraine transport wheat to import-dependent North African countries. Russia and Ukraine enter a war of attrition, with the

situation becoming more intense than in the beginning. At the same time, the wheat North American farmers planted in the spring to fill supply shortages in March-April matures in July-August. Influence of many reasons, the abnormal disturbance of wheat prices tended to normalize back to the pre-war level. Nevertheless, the war-induced Granger causality continued. The past Black Sea wheat could no longer be used for price forecasting of future Ukrainian wheat and CME wheat. The other relationships, such as Ukrainian wheat constituting Granger causality for Black Sea wheat, were maintained. Our study, in part I, focused on the effect of marginal effects on Granger causality for each additional month of the time series for the entire war period. When the sample size becomes large enough, as the war continues, we find that Granger causality is maintained among the variables; this may be due to the inclusion of pre-war time series data.

Table 9: Fixed six months of prewar Granger causality

	5/2021-10/2021	6/2021-11/2021	7/2021-12/2021	8/2021-1/2022
(ukr,black)	0.0005765	0.0001128	0.001226	0.003712
(black,ukr)	0.5805	0.5361	0.9465	0.7587
(ukr,cme)	0.01168	0.0514	0.1005	0.483
(cme,ukr)	0.3848	0.2784	0.3358	0.192
(black,cme)	0.4375	0.08904	0.1551	0.07222
(cme,black)	0.08551	0.0534	0.1198	0.07949

In the second part of the time series data, we choose a six-month fixed length to explore the Granger causality variation among three wheat futures in the pre-war, mid-war, and later stages. As shown in Table 9, we fix the periods spanned by the time series and the sample size. The choice of a fixed six-month period makes the pre-war data more meaningful for contemporaneous comparisons than Table 6's approach of increasing the number of months of data because the last data are not affected by the earlier data sets. For example, in the time series

data from July 2021 to December 2021, the hypothesis of Granger causality is rejected for all five except for Black Sea wheat, which constitutes Granger causality for Ukrainian wheat. The uncertainty about the future price of wheat when approaching the outbreak of the Russian-Ukrainian war and the influence of multiple factors makes it challenging to use short-term 6-month data for speculation.

Table 10: Fixed six months of early war Granger causality

	9/2021-2/2022	10/2021-3/2022	11/2021-4/2022	12/2021-5/2022	1/2022-6/2022	2/2022-7/2022
(ukr,black)	0.009391	0.443	0.2989	0.8363	0.795	0.8557
(black,ukr)	0.7475	0.009932	0.001986	0.0002623	0.007576	0.00547
(ukr,cme)	0.004698	0.003796	0.01329	0.01698	0.003779	0.006969
(cme,ukr)	0.2878	0.002659	0.08308	0.1307	0.07223	0.06583
(black,cme)	0.141	0.01669	0.06723	0.1167	0.02887	0.04101
(cme,black)	0.08997	0.003411	0.2687	0.4333	0.1364	0.0736

After the war broke out at the end of February 2022, specific wheat not initially Granger causally related showed intensive, mutually able predictive relationships. In Table 10, this situation carries over to the fixed six-month time series analysis. The regional supply of Ukrainian and Black Sea wheat has a Granger causality for CME wheat from October 2021 to March 2022 because of the wheat price increase driven by the first month of the war. However, Black Sea wheat loses its Granger causality with Ukrainian wheat earlier than Table 7, primarily when the pre-war dataset and the long-standing forecast relationship affect the war's beginning. If we observe in shorter time series, the war that broke out resulted in no trade between them and the blockade and embargo Russia imposed on Ukraine, severing the price causality between the two wheat producers in a much shorter period.

Table 11: Fixed six months of later war Granger causality

	3/2022-8/2022	4/2022-9/2022	5/2022-10/2022	6/2022-11/2022	7/2022-12/2022	8/2022-1/2023	9/2022-2/2023
(ukr,black)	0.9314	0.1289	0.1396	0.3258	0.8769	0.9113	0.06788
(black,ukr)	0.05439	0.008025	0.01699	0.3097	0.7033	0.4978	0.01739
(ukr,cme)	0.04379	0.004742	0.006763	0.2299	0.9392	0.7505	0.4581
(cme,ukr)	0.9678	0.3752	0.5491	0.8279	0.8775	0.2465	0.002394
(black,cme)	0.06916	0.004903	0.001978	0.0227	0.5175	0.1364	0.01966
(cme,black)	0.3794	0.3479	0.2766	0.7233	0.2342	0.8303	0.909

Different from the first part, this Granger causality due to the war only lasts for a short time in the later part of the war. In Table 11, Ukrainian wheat, Black Sea wheat, and CME wheat have almost lost any statistically significant causality after June 2022 to November 2022, e.g., it is no longer possible to use the CME wheat price in the previous period to make forecasts for the Ukrainian wheat price in the next six months. The result is quite different from the Table 8 data, where the Granger causality generated between all the data before and during the war was able to influence the post-war ones due to the larger sample size, allowing the p-value to retain significance all the time and the Granger causality between them to perpetuate. However, if we focus on local time changes rather than the entire period, this Granger causality has no long-term cointegration relationship. In re-running the Engle-Granger Test, we found that at least one of the t-statistic values among the three kinds of wheat in the full-time period of Table 11 (colored purple) did not satisfy the premise of rejecting the original hypothesis. The result demonstrates those variables no longer constitute a long-term valid cointegration relationship, and there is a spurious regression. Since all the periods in Table 11 are during the outbreak of the war and no pre-war wheat price data exists, it is unreliable to use the pre-war wheat prices to predict the post-war prices six months later. The chaos generated by the war

prevents them from generating a statistically significant temporal sequential relationship, and only local time periods generate Granger causality.

Table 12: Residual results of the Engle-Granger test

t-statistic value	5/2021-10/2021	5/2021-10/2021	7/2021-12/2021	8/2021-1/2022	9/2021-2/2022	10/2021-3/2022	11/2021-4/2022	12/2021-5/2022	1/2022-6/2022
(ukr~black)	-2.2208	-2.4334	-3.0239	-2.3014	-1.7649	-2.3604	-3.0458	-2.5849	-2.4922
(ukr~cme)	-1.807	-1.9916	-2.236	-2.5219	-1.3278	-2.4866	-2.6197	-2.4652	-2.0614
(black~cme)	-2.1346	-2.0318	-2.0836	-2.8971	-0.9523	-1.5041	-1.9925	-1.8901	-1.5959

t-statistic value	2/2022-7/2022	3/2022-8/2022	4/2022-9/2022	5/2022-10/2022	6/2022-11/2022	7/2022-12/2022	8/2022-1/2023	9/2022-2/2023
(ukr~black)	-2.2338	-2.1642	-2.0252	-1.8763	-0.4936	-0.8694	-1.178	-1.4826
(ukr~cme)	-1.951	-1.1629	-0.7235	-0.8473	-0.9868	-0.83	-2.3217	-3.1826
(black~cme)	-1.7292	-0.6863	-0.8643	-0.8335	-1.1945	-1.5908	-2.4031	-1.4874

Table 12 shows the E-G test results for May 2021 to Feb 2023 in the second part of the two sheets. The parts marked in red refer to the cases there no long-term cointegration relationship existed between the two variables. The first two months of the war outbreak and the datasets after August 2022 are high-frequency periods in which the t-statistic value could not pass the E-G test. The situation does not occur in the first part because we keep extending the time series data, and the effect of the extremes on the long-term cointegration relationship is weakened with the expanded sample size. However, when considered over a six-month local period, the effect of war on Granger causality is dramatic. The inability to pass the E-G test can also demonstrate that the chaotic nature of war brings about uncertainty in price forecasts in the time series.

CHAPTER 7. Discussion and Conclusion

The current Russia-Ukraine war (2022-2023) poses challenges to wheat prices worldwide, and the price shock for the grain is a massive blow to countries that depend on wheat imports. In addition to the economic losses, our study focuses on the fact that the

disruption of wheat commodity prices is not due to a single cause of war. Global commodity markets are integrated, and it is unreasonable to assume that dynamic adjustments to the equilibrium do not occur under war conditions. The overall inflationary environment and rising freight costs are the essential factors driving regional wheat price increases. Examining the link between war and wheat commodity prices is necessary to consider the impact of multiple intrinsic and extrinsic factors. Our study uses the spatial equilibrium model to explore synthetically the supply relationship, cost, and price between two regions when supply is restricted, embargoed, and transportation costs rise. The expected reduction in wheat supply leads to an increase in global prices. In the short term, the increase is significant, but as world conditions adjust, a new equilibrium emerges, global wheat cultivation increases, demand decreases, and prices increase. Even with lifting the embargo, Ukraine's exports suffered from higher transportation costs due to a lack of insurance and increased risks for shippers and ocean transportation.

To better observe whether there is a valid price prediction relationship between wheat in different periods, our study used the VAR model to monitor the changes in Granger causality between Ukrainian wheat, Black Sea wheat, and CME wheat in different stages of the war. By viewing the marginal effect of the increasing one-month time series (first part) and the fixed six-month time series (second part), we found that at the beginning of the war, around March 2022, there was a statistically significant temporal sequential prediction relationship between the three kinds of wheat under the influence of war. Furthermore, the original Granger causality of Black Sea wheat to Ukrainian wheat was severed because of the war, which became particularly evident in the second part. The price prediction relationship from the war continued in the first part because of the large sample size and the inclusion of previous time series data.

The Granger causality disappears in the second part because it is unreliable to use a specific wheat price at the beginning of the war to predict the wheat price in the later war over six months. That is, historical price relationships were fractured, and our results confirm that the long-term cointegration relationship at local times was disrupted by extreme data fluctuations caused by the war. In this case, generating Granger causality is most likely a spurious regression. The chaotic nature of war makes price prediction challenging, and our study shows that the predictive relationship between prices of different wheat in the time series of a full-blown war is nonexistent.

Finally, there have been no significant outbreaks of war since WWII that have had a significant impact on global agricultural commodities, and therefore with the exception of impact assessments in local military activities, the topic of 'war and commodities' has not been widely addressed. Working (1941) warns us that attributing commodity price movements to war itself, without considering other factors such as market conditions prior to the war, or global responses to the war could lead to erroneous attribution of events. In addition, there is no stand-alone theory of war. Instead, the theory is rooted in the immediate impacts of the war on local and global supplies, and in a general welfare, spatial equilibrium context. The rapid rise in wheat prices at the start of Russia's invasion of Ukraine in February 2022 was short-lived as the scope of the war developed, and global supply and demand conditions adjusted. Other factors such as the effect of blockade or rising transportation costs due to loss of insurance and risk premia are difficult to measure and show causality on a day-to-day basis. Instead, what can be observed is causality itself. In this paper, the central proposition was that war affected global wheat prices. But as the war continued and global wheat prices fell to near pre-war levels, it cannot be said that war both causes prices to rise and causes prices to fall. Instead, we focused

on the changing metric of Granger causality, which is determinative in establishing that there is an economic relationship between war and commodities. The Granger causal relationships between Ukrainian, Black Sea, and CME wheat futures prices were stable before the war, but leading up to and following the start of the war our vector autoregression (VAR) results across overlapping 6-month time scales, indicating that historical Granger relationships fractured. This study has shown that the fracturing of historical Granger causal or correlated relationships because of the war is in-fact causal. Thus, we conclude in our study of war and commodities that the most enduring impact is the breakdown and realignment of historical trade relationships and we suggest that this realignment will persist until the war's end.

References

Dahir, A. L., & Peltier, E. (2022, July 22). *'the deal should help us breathe': Africa welcomes Russia-Ukraine grain deal.* The New York Times. Retrieved March 30, 2023, from https://www.nytimes.com/2022/07/23/world/europe/the-deal-should-help-us-breathe-africa-welcomes-russia-ukraine-grain-deal.html

Hankins, M. (2023, March 20). *Russia agrees to extend the Black Sea Grain deal*. Barchart.com. Retrieved March 23, 2023, from https://www.barchart.com/story/news/15224710/russia-agrees-to-extend-black-sea-grain-deal

Hirtenstein, A. (2023, February 26). *Sanctions net widens to catch Russia's Middle East Shipping Company*. The Wall Street Journal. Retrieved March 22, 2023, from https://www.wsj.com/articles/sanctions-net-widens-to-catch-russias-middle-east-oil-shipper-43938b0e

India: India bans wheat exports due to domestic supply concerns. USDA Foreign Agricultural Service. (2023, March 27). Retrieved March 29, 2023, from https://www.fas.usda.gov/data/india-india-bans-wheat-exports-due-domestic-supply-concerns

Kirby, P. (2023, February 24). *Has putin's war failed and what does Russia want from Ukraine?* BBC News. Retrieved March 22, 2023 from https://www.bbc.com/news/world-europe-56720589

Martin, L. J. (1981). Quadratic single and multi-commodity models of spatial equilibrium: A simplified exposition. *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, *29*(1), 21–48. https://doi.org/10.1111/j.1744-7976.1981.tb02151.x

Nandy, S., & Kaderabek-Vela, A. (2022, December 23). *Commodities 2023: Canada set to become a major wheat supplier in H1*. S&P Global Commodity Insights. Retrieved March 29, 2023, from https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/122322-Canada-set-to-become-major-wheat-supplier-in-h1-2023

Paris, C., & Benoit, B. (2022, February 26). *Ukraine closes Sea of Azov amid military action by Russia*. The Wall Street Journal. Retrieved April 10, 2023, from https://www.wsj.com/livecoverage/russia-ukraine-latest-news/card/ukraine-closes-sea-of-asov-amid-military-action-by-Russia-Sg4Q4idnoBwfzSAOZXsd

RUTA, M. (n.d.). *How the war in Ukraine is reshaping World Trade and Investment*. World Bank Blogs. Retrieved March 22, 2023, from

https://blogs.worldbank.org/developmenttalk/how-war-ukraine-reshaping-world-trade-and-investment

Takayama, T., & Judge, G. G. (1971). *Spatial and temporal price and allocation models*. North-Holland.

Team, T. V. J. (2023, March 9). *Ukraine in maps: Tracking the war with Russia*. BBC News. Retrieved April 10, 2023, from https://www.bbc.com/news/world-europe-60506682

Turvey, C. G., Zhang, X., & Gomez, M. I. (2022). The effects of the 2018-2019 Sino-America Trade War on the relationship between Chicago and Dalian Soybean Futures Prices. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4131557

Wheat Mar '24 futures interactive chart. Barchart.com. (n.d.). Retrieved April 18, 2023, from https://www.barchart.com/futures/quotes/ZWH24/interactive-chart

Working, H. (1940). War and commodity prices. *Journal of the American Statistical Association*, *35*(210), 309–324. https://doi.org/10.1080/01621459.1940.10502043