A Multiperiod, Multicommodity, Capacitated International Agricultural Trade Network Equilibrium Model with Applications to Ukraine in Wartime

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Abstract. The world is facing immense challenges because of increasing strife and the impacts of climate change with accompanying disasters, both sudden-onset as well as slow-onset ones, which have affected the trade of agricultural commodities needed for food security. In this paper, a multiperiod, multicommodity, international, agricultural trade network equilibrium model is constructed with capacity constraints on the production, transportation, and storage of agricultural commodities. The model allows for multiple routes between supply and demand country markets, different modes of transport, and storage in the producing and consuming countries as well as in the intermediate countries. The generality of the underlying functions, coupled with the capacity constraints, allow for the modeling of competition among agricultural commodities for production, transportation, and storage. The capacity constraints also enable the quantification of various disaster-related disruptions to production, transportation, and storage on the volumes of commodity flows as well as on the prices. A series of numerical examples inspired by the effects of Russia's full-scale invasion of Ukraine on agricultural trade is presented, and the results are analyzed to provide insights into food insecurity issues caused by the war.

Keywords: networks • international trade • spatial price equilibrium • agriculture • disruptions • Ukraine

Acknowledgment and Dedication

This presentation is dedicated to farmers in Ukraine and everywhere in the world.

The authors acknowledge the partnership between the University of Massachusetts Amherst and the Kyiv School of Economics, which facilitated this research.

UMass Amherst KSE | Kyiv School of Economics

The War in Ukraine

The full-scale invasion of Ukraine by Russia on February 24, 2022 has resulted in immense losses of lives and an increase in human suffering. It has severely impacted the economy of Ukraine with repercussions globally.

The Impacts on Ukraine's Agricultural Sector

- **Between 20 to 30% of the arable land in Ukraine is estimated to remain idle due to mining and other damages because of the full-scale invasion, resulting in around a 40% decrease in the production of grains in Ukraine.**

The Impacts on Ukraine's Agricultural Sector

- **The blockade of the Ukrainian Black Sea ports, which used to handle around 90% of the grain exports from Ukraine, caused a global shortage of grains.**
- **The war has cost Ukraine around 15% of its grain storage capacity.**

The Impacts on Global Food Security and Economy

- **Reports indicate a rise of around 17% in the population facing food insecurity worldwide due to the full-scale invasion.**
- **The disruptions in the exports of Ukrainian grain can cost the global economy more than 1.6 billion dollars.**
- **Many countries heavily rely on Ukrainian grains, especially vulnerable countries in the Middle East and North Africa (MENA) region.**

The Black Sea Grain Initiative

- **The Black Sea Grain Initiative, facilitated by Turkey and the United Nations, allowed for the limited passage of grain shipments from selected Ukrainian ports on the Black Sea from August 1, 2022.**

- **As of July 17, 2023, Russia has suspended the initiative, imposing a severe food security risk worldwide.**

Literature Review

• The theory of variational inequalities (cf. Nagurney (1999, 2006)) is the methodology used to develop the modeling and algorithmic framework in this paper.

• Spatial price equilibrium models were first introduced in the groundbreaking contributions of Samuelson (1952) and Takayama and Judge (1964, 1971) and are partial equilibrium models under perfect competition.

• Spatial price equilibrium models have been widely used in modeling disaster scenarios and relevant food security issues, the trade of agricultural products, and in the assessment of the impacts of different policy instruments.

• Nagurney et al. (2023) developed a multicommodity international spatial price equilibrium model with exchange rates in which transportation through multiple intermediate countries was possible; however, the model did not include storage and imposed no capacities.

• Nagurney et al. (2024) constructed a multicommodity international agricultural spatial price equilibrium model with bounds on the production and transportation of commodities, but the model included only one period, and transportation through multiple countries was not considered.

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Abstract. The world is facing immense challenges because of increasing strife and the impacts of climate change with accompanying disasters, both sudden-onset as well as slow-onset ones, which have affected the trade of agricultural commodities needed for food security. In this paper, a multiperiod, multicommodity, international, agricultural trade network equilibrium model is constructed with capacity constraints on the production, transportation, and storage of agricultural commodities. ... A series of numerical examples inspired by the effects of Russia's full-scale invasion of Ukraine on agricultural trade is presented, and the results are analyzed to provide insights into food insecurity issues caused by the war.

Keywords: networks • international trade • spatial price equilibrium • agriculture • disruptions • Ukraine

1. Introduction

The full-scale invasion of Ukraine by Russia on February 24, 2022, has resulted in immense losses of lives and an increase in human suffering. ...

Quantification of International Trade Network Performance
Under
uptions to Supply, Transportation, and Demand Capacity, and Exchange Rates in Disas

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Revised March 2024

Prepared for: Dynamics of Disasters - From Natural Phenomena to Human Activity, I.S Kotsireas et al., Editors, Springer Nature Switzerland AG.

Abstract: Both sudden-onset and slow-onset disasters are causing disruptions to global trade, impacting the availability and affordability of commodities from agricultural to mineral ones. In this paper, we develop a multicommodity international trade network equilibrium model under disaster scenarios with distinct probabilities of the occurrence of the disasters and their impacts on the capacities associated with production, transportation, and consumption. The disaster scenarios can also affect the exchange rates. We state the governing equilibrium conditions and derive the variational inequality formulation in commodity path flow variables and Lagrange multipliers associated with the capacity constraints. For each disaster scenario, we construct an international trade network performance measure, followed by a unified performance measure that includes all the disasters and their probabilities. Robustness is then quantified as the difference between the network performance under no disruptions and the unified performance measure. An international trade network component performance indicator is also given to assess the impacts of the complete removal of trade network supply markets, demand markets, and/or transportation routes. The modeling framework is then illustrated through a series of numerical examples, motivated by Russia's war on Ukraine. The work is of relevance to decision-makers and policy-makers.

Key words: networks, international trade, disasters, disruptions, robustness, variational inequalities

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Innovative Applications of O.R.

Multicommodity international agricultural trade network equilibrium: Competition for limited production and transportation capacity under disaster scenarios with implications for food security

Anna Nagurney[a,*], Dana Hassani[a], Oleg Nivievskyi[b], Pavlo Martyshev[b]

1. Introduction

Our planet and people are being faced with immense challenges brought about by disasters ranging from those caused by natural phenomena ...

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Exchange rates and multicommodity international trade: insights from spatial price equilibrium modeling with policy instruments via variational inequalities

Anna Nagurney[1] · Dana Hassani[1] · Oleg Nivievskyi[2] · Pavlo Martyshev[2]

Received: 29 December 2022 / Accepted: 2 May 2023

Abstract
In this paper, we construct a multicommodity international trade spatial price equilibrium model of special relevance to agriculture in which exchange rates are included along with policy instruments in the form of tariffs, subsidies as well as quotas. The model allows for multiple trade routes between country origin nodes and country destination nodes and these trade routes can include different modes of transportation and transport through distinct countries. We capture the impacts of exchange rates through the definition of effective path costs and identify the governing multicommodity international trade spatial price equilibrium conditions, which are then formulated as a variational inequality problem in product path flows. Existence results are established and a computational procedure presented. The illustrative numerical examples and a case study are inspired by the impacts of the war against Ukraine on agricultural trade flows and product prices. The modeling and algorithmic framework allows for the quantification of the impacts of exchange rates and various trade policies, as well as the addition or deletion of supply markets, demand markets and/or routes, on supply and demand market prices in local currencies, and on the volume of product trade flows with implications for food security.

Keywords Exchange rates · Spatial price equilibrium · International trade · Networks · Variational inequalities · Agriculture

1 Introduction

Exchange rates represent the value (price) of one currency relative to another currency. They are important economic parameters in international trade, with changes in the exchange rate affecting the decision-making of individuals, businesses, and governments. A separate

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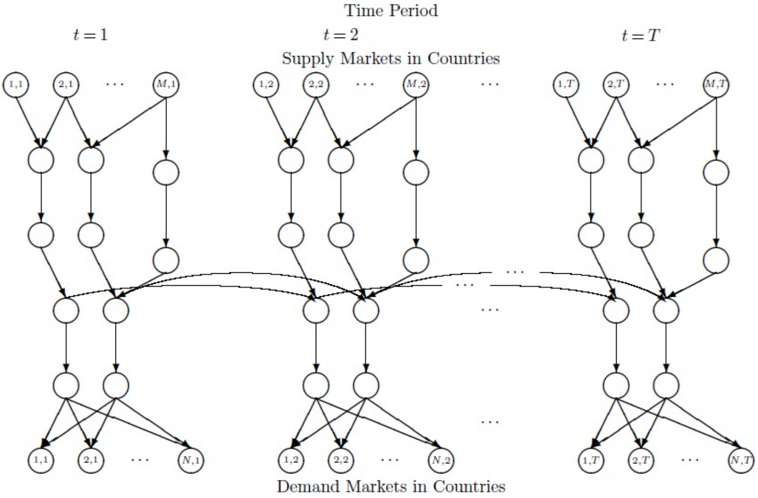
Contributions of This Paper

- The model simultaneously includes bounds on production output, transportation, and storage.
- The model allows for the storage of agricultural commodities in the intermediate countries as the commodities are transported from origin countries to destination countries as well as in the producing origin country and/or the destination consuming country).
- The underlying functions in the model can be nonlinear and asymmetric.
- The generality of the underlying functions, along with the capacity constraints and their associated Lagrange multipliers, allow for the modeling of competition among agricultural commodities for production, transportation, and storage.
- The numerical examples are drawn from an ongoing war with a global impact on food security.

The Multiperiod International Trade Model



Notation for The Multiperiod International Trade Model

Notation	Parameter Definition
$u_{i,t}$	supply capacity at supply node i; $i \in \mathcal{I}$, in time period t; $t \in \mathcal{T}$.
u_a^{τ}	transportation capacity on transportation link a; $a \in \mathcal{L}^{\tau}$.
u_a^{σ}	inventory capacity on inventory link a; $a \in \mathcal{L}^{\sigma}$.
Notation	**Variable Definition**
Q_p^h	the flow of commodity h; $h \in \mathcal{H}$, on path p; $p \in \mathcal{P}$. We group all the commodity path flows into the vector $Q \in \mathcal{R}_+^{Hn_{\mathcal{P}}}$, where $n_{\mathcal{P}}$ is the number of paths in the network.
f_a^h	the flow of commodity h; $h \in \mathcal{H}$, on link a; $a \in \mathcal{L}$. We group all the commodity link flows into the vector $f \in \mathcal{R}_+^{Hn_{\mathcal{L}}}$, where $n_{\mathcal{L}}$ is the number of links in the network.
$s_{i,t}^h$	the supply of the commodity h; $h \in \mathcal{H}$, at supply node i; $i \in \mathcal{I}$, in time period t; $t \in \mathcal{T}$. We group all the commodity supplies into the vector $s \in \mathcal{R}_+^{HMT}$.
$d_{j,t'}^h$	the demand for the commodity h; $h \in \mathcal{H}$, at demand node j; $j \in \mathcal{J}$, in time period t'; $t' \in \mathcal{T}$. We group all the commodity demands into the vector $d \in \mathcal{R}_+^{HNT}$.
$\lambda_{i,t}$	the Lagrange multiplier associated with the supply capacity constraint at supply node i; $i \in \mathcal{I}$, in time period t; $t \in \mathcal{T}$. We group all such Lagrange multipliers into the vector $\lambda \in \mathcal{R}_+^{MT}$.
μ_a	the Lagrange multiplier associated with the transportation capacity constraint on transportation link a; $a \in \mathcal{L}^{\tau}$. We group all such Lagrange multipliers into the vector $\mu \in \mathcal{R}_+^{n_{\mathcal{L}^{\tau}}}$, where $n_{\mathcal{L}^{\tau}}$ is the number of transportation links in the trade network.
γ_a	the Lagrange multiplier associated with the inventory capacity constraint on inventory link a; $a \in \mathcal{L}^{\sigma}$. We group all such Lagrange multipliers into the vector $\gamma \in \mathcal{R}_+^{n_{\mathcal{L}^{\sigma}}}$, where $n_{\mathcal{L}^{\sigma}}$ is the number of inventory links in the trade network.
Notation	**Function Definition**
$\pi_{i,t}^h(Q)$	the supply price function for commodity h; $h \in \mathcal{H}$, at supply node i; $i \in \mathcal{I}$, in time period t; $t \in \mathcal{T}$.
$\rho_{j,t'}^h(Q)$	the demand price function for commodity h; $h \in \mathcal{H}$, at demand node j; $j \in \mathcal{J}$, in time period t; $t \in \mathcal{T}$.
$c_a^h(Q)$	the unit link cost associated with the commodity h; $h \in \mathcal{H}$, on link a; $a \in \mathcal{L}$.

The Multiperiod International Trade Model

The commodity path flows must be nonnegative:

$$Q_p^h \geq 0, \quad \forall h \in \mathcal{H}, p \in \mathcal{P}. \tag{1}$$

The cost on a path p for commodity h is given by the following expression:

$$C_p^h = \sum_{a \in \mathcal{L}} \delta_{a,p} c_a^h(Q), \quad \forall h \in \mathcal{H}, p \in \mathcal{P}, \tag{2}$$

where $\delta_{a,p} = 1$, if link a is contained in path p, and is 0, otherwise; i.e., the cost on a path for a commodity is equal to the sum of the costs on the links that make up the path for the commodity.

The Equilibrium Conditions

Definition 1: The Equilibrium Conditions

A path flow and Lagrange multiplier pattern $(Q^*, \lambda^*, \mu^*, \gamma^*) \in \mathcal{K}^1 \equiv \{(Q, \lambda, \mu, \gamma) | Q \in \mathcal{R}_+^{Hn_\mathcal{P}}, \lambda \in \mathcal{R}_+^{MT}, \mu \in \mathcal{R}_+^{n_{\mathcal{L}^\tau}}, \gamma \in \mathcal{R}_+^{n_{\mathcal{L}^\sigma}}\}$ *is an equilibrium under capacities if the following conditions hold:*

$$\pi_{i,t}^h(Q^*) + C_p^h(Q^*) + \lambda_{i,t}^* + \sum_{a \in \mathcal{L}^\tau} \delta_{a,p}\mu_a^* + \sum_{a \in \mathcal{L}^\sigma} \delta_{a,p}\gamma_a^* - \rho_{j,t'}^h(Q^*) \geq 0 \ \perp \ Q_p^{h*} \geq 0$$

$$\forall p \in \mathcal{P}_{j,t'}^{i,t}, h \in \mathcal{H} \tag{3}$$

$$u_{i,t} - \sum_{h \in \mathcal{H}} \sum_{p \in \mathcal{P}^{i,t}} Q_p^{h*} \geq 0 \ \perp \ \lambda_{i,t}^* \geq 0 \ \forall i \in \mathcal{I}, t \in \mathcal{T} \tag{4}$$

$$u_a^\tau - \sum_{h \in \mathcal{H}} \sum_{p \in \mathcal{P}} \delta_{a,p} Q_p^{h*} \geq 0 \ \perp \ \mu_a^* \geq 0 \ \forall a \in \mathcal{L}^\tau \tag{5}$$

$$u_a^\sigma - \sum_{h \in \mathcal{H}} \sum_{p \in \mathcal{P}} \delta_{a,p} Q_p^{h*} \geq 0 \ \perp \ \gamma_a^* \geq 0 \ \forall a \in \mathcal{L}^\sigma. \tag{6}$$

Variational Inequality Formulation

The Variational Inequality Formulation in Path Flows and Lagrange Multipliers

A path flow and Lagrange multiplier pattern $(Q^*, \lambda^*, \mu^*, \gamma^*) \in \mathcal{K}^1$ *is an equilibrium under capacities according to Definition 1 if and only if it satisfies the variational inequality:*

$$\sum_{h\in\mathcal{H}}\sum_{i\in\mathcal{I}}\sum_{j\in\mathcal{J}}\sum_{t\in\mathcal{T}}\sum_{t'\in\mathcal{T}}\sum_{p\in\mathcal{P}^{i,t}_{j,t'}}\left[\pi^h_{i,t}(Q^*) + C^h_p(Q^*) + \lambda^*_{i,t} + \sum_{a\in\mathcal{L}^\tau}\delta_{a,p}\mu^*_a + \sum_{a\in\mathcal{L}^\sigma}\delta_{a,p}\gamma^*_a - \rho^h_{j,t'}(Q^*)\right]$$

$$\times\left[Q^h_p - Q^{h*}_p\right] + \sum_{i\in\mathcal{I}}\sum_{t\in\mathcal{T}}\left[u_{i,t} - \sum_{h\in\mathcal{H}}\sum_{p\in\mathcal{P}^{it}}Q^{h*}_p\right]\times\left[\lambda_{i,t} - \lambda^*_{i,t}\right]$$

$$+\sum_{a\in\mathcal{L}^\tau}\left[u^\tau_a - \sum_{h\in\mathcal{H}}\sum_{p\in\mathcal{P}}\delta_{a,p}Q^{h*}_p\right]\times\left[\mu_a - \mu^*_a\right]$$

$$+\sum_{a\in\mathcal{L}^\sigma}\left[u^\sigma_a - \sum_{h\in\mathcal{H}}\sum_{p\in\mathcal{P}}\delta_{a,p}Q^{h*}_p\right]\times\left[\gamma_a - \gamma^*_a\right] \geq 0, \quad \forall (Q,\lambda,\mu,\gamma)\in\mathcal{K}^1. \tag{7}$$

Numerical Examples

• A series of numerical examples inspired by the disruptions to the international trade of agricultural commodities caused by Russia's full-scale invasion of Ukraine are presented. **All data is contained in our paper**.

• The examples focus on the export of agricultural commodities of wheat and corn from Ukraine to Lebanon and Egypt.

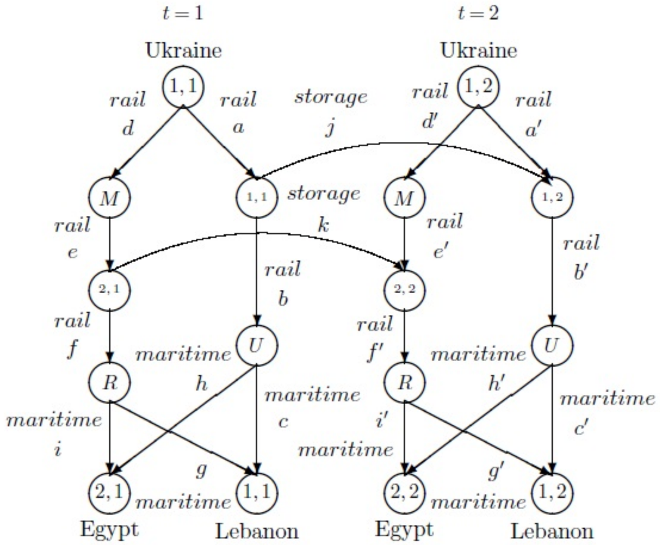
• All examples consist of two periods corresponding to the projected yearly commodity shipments in metric tons.

• Lebanon and Egypt are two representative MENA countries significantly affected by the war in terms of the food security of their populations.

• The functions in these examples are constructed based on the data used in Nagurney et al. (2023) and Nagurney et al. (2024).

• The algorithmic framework used to solve the examples is that of the Modified Projection Method of Korpelevich (1977).

Network Topology



Path Descriptions

Lebanon, $t = 1$

• $p_1 = (a, b, c)$: Rail transport from farms to a storage facility in Ukraine, rail transport from the storage facility to a Black Sea port in Ukraine, and maritime transport to Lebanon, all in the first period.

• $p_2 = (d, e, f, g)$: Rail transport from farms to Moldova, rail transport to a storage facility in Moldova, rail transport from the storage facility to a Black Sea port in Romania, and maritime transport to Lebanon, all in the first period.

Egypt, $t = 1$

• $p_3 = (a, b, h)$: Rail transport from farms to a storage facility in Ukraine, rail transport from the storage facility to a Black Sea port in Ukraine, and maritime transport to Egypt, all in the first period.

• $p_4 = (d, e, f, i)$: Rail transport from farms to Moldova, rail transport to a storage facility in Moldova, rail transport from the storage facility to a Black Sea port in Romania, and maritime transport to Egypt, all in the first period.

Path Descriptions

Lebanon and Egypt, $t = 2$

Paths p_5**,** p_6**,** p_7**, and** p_8 **are the same as the first four paths, respectively, but all in the second period and with links denoted with a ’.**

Paths with Storage Links Joining First and Second Periods

To Lebanon

- $p_9 = (a, j, b', c')$
- $p_{10} = (d, e, k, f', g')$

To Egypt

- $p_{11} = (a, j, b', h')$
- $p_{12} = (d, e, k, f', i)$

Path Description

- p_9: Rail transport from farms to a storage facility in Ukraine in the first period, storage from the first period to the second period, rail transport from the storage facility to a Black Sea port in Ukraine, and maritime transport to Lebanon.
- p_{10}: Rail transport from farms to Moldova in the first period, rail transport to a storage facility in Moldova in the first period, storage from the first period to the second period, rail transport from the storage facility to a Black Sea port in Romania, and maritime transport to Lebanon.
- p_{11}: Rail transport from farms to a storage facility in Ukraine in the first period, storage from the first period to the second period, rail transport from the storage facility to a Black Sea port in Ukraine, and maritime transport to Egypt.
- p_{12}: Rail transport from farms to Moldova in the first period, rail transport to a storage facility in Moldova in the first period, storage from the first period to the second period, rail transport from the storage facility to a Black Sea port in Romania, and maritime transport to Egypt.

Numerical Example Scenarios

Example 1: Single Commodity, Prior to Full-Scale Invasion

In Example 1, there is a single commodity of wheat, i.e., $H = 1$. Furthermore, the scenario is one before the full-scale invasion.

Example 2: Two Commodities, Prior to Full-Scale Invasion

In Example 2, there are two commodities, wheat and corn; i.e., $h = 1, 2$. The time horizon is before the full-scale invasion. Similar capacities to those in Example 1 are imposed on two commodities.

Example 3: Two Commodities, First Period Prior to the Full-Scale Invasion, Second Period After

In Example 3, the first period is before the full-scale invasion and the second period corresponds to the situation after Russia's full-scale invasion, when prices were significantly affected, maritime transportation from Ukrainian Black Sea ports was blockaded, and production was severely disrupted due to damages to arable land.

Example 4: Two Commodities: First Period is Before the Black Sea Gran Initiative, Second Period is After It

In Example 4, the effect of establishing the Black Sea Grain Initiative is assessed. The first period is before the the initiative, and the second period is after it. The transportation capacity on links c' and h' are restored to those before the invasion since the initiative provided a safe corridor the export of grains. The damages to storage facilities in Ukraine have resulted in a decrease in the storage capacity on inventory link j.

Results for Commodity 1 (Wheat)

	Example 1	Example 2	Example 3	Example 4
$Q^{1*}_{p_1}$	571,868	532,483	512,066	0
$Q^{1*}_{p_2}$	0	0	0	0
$Q^{1*}_{p_3}$	1,917,419	1,799,439	1,730,628	0
$Q^{1*}_{p_4}$	0	0	0	0
$Q^{1*}_{p_5}$	571,870	532,484	0	185,660
$Q^{1*}_{p_6}$	0	0	0	0
$Q^{1*}_{p_7}$	1,917,410	1,799,431	0	518,442
$Q^{1*}_{p_8}$	0	0	0	0
$Q^{1*}_{p_9}$	0	0	0	27,213
$Q^{1*}_{p_{10}}$	0	0	91,669	118,989
$Q^{1*}_{p_{11}}$	0	0	0	359,996
$Q^{1*}_{p_{12}}$	0	0	303,271	180,273
$s^{1*}_{1,1}$	2,489,287	2,331,922	2,637,635	686,470
$s^{1*}_{1,2}$	2,489,280	2,331,916	0	704,102
$d^{1*}_{1,1}$	571,868	532,483	512,066	0
$d^{1*}_{1,2}$	571,870	532,484	91,669	331,861
$d^{1*}_{2,1}$	1,917,419	1,799,439	1,730,628	0
$d^{1*}_{2,2}$	1,917,410	1,799,431	303,271	1,058,711
$\pi^{1}_{1,1}$	\$262.45	\$262.56	\$264.16	\$103.75
$\pi^{1}_{1,2}$	\$262.45	\$262.56	\$100	\$103.82
$\rho^{1}_{1,1}$	\$344.27	\$346.04	\$346.96	\$530
$\rho^{1}_{1,2}$	\$344.27	\$346.04	\$525.87	\$515.07
$\rho^{1}_{2,1}$	\$341.24	\$343.01	\$344.04	\$530
$\rho^{1}_{2,2}$	\$341.24	\$343.01	\$525.45	\$514.12

Results for Commodity 2 (Corn)

	Example 2	Example 3	Example 4
$Q^{2*}_{p_1}$	162,194	157,295	0
$Q^{2*}_{p_2}$	0	0	0
$Q^{2*}_{p_3}$	733,834	710,866	0
$Q^{2*}_{p_4}$	0	0	0
$Q^{2*}_{p_5}$	162,194	0	72,929
$Q^{2*}_{p_6}$	0	0	0
$Q^{2*}_{p_7}$	733,836	0	223,055
$Q^{2*}_{p_8}$	0	0	0
$Q^{2*}_{p_9}$	0	0	6,938
$Q^{2*}_{p_{10}}$	0	17,862	40,491
$Q^{2*}_{p_{11}}$	0	0	105,854
$Q^{2*}_{p_{12}}$	0	87,217	160,248
$s^{2*}_{1,1}$	896,028	973,241	313,530
$s^{2*}_{1,2}$	896,030	0	295,983
$d^{2*}_{1,1}$	162,194	157,295	0
$d^{2*}_{1,2}$	162,194	17,862	120,358
$d^{2*}_{2,1}$	733,834	710,866	0
$d^{2*}_{2,2}$	733,836	87,217	489,156
$\pi^{2}_{1,1}$	\$253.62	\$255.01	\$94.51
$\pi^{2}_{1,2}$	\$253.62	\$90	\$94.37
$\rho^{2}_{1,1}$	\$345.41	\$345.84	\$520
$\rho^{2}_{1,2}$	\$345.41	\$518.39	\$509.17
$\rho^{2}_{2,1}$	\$341.65	\$342.23	\$520
$\rho^{2}_{2,2}$	\$341.65	\$517.82	\$507.77

- A zero path flow means that no trade is happening on that specific path, i.e., no commodity is being shipped between Ukraine and the destination country via that specific route. Blockades and damages to transportation infrastructure (i.e., zero capacity) or high transportation and storage costs due to risks result in a path not being used.

- In Example 1 and 2, no storage is observed since the demand in both demand nodes can be met more cheaply from the supply of the same period.

- In Example 3, due to the blockade of the Ukrainian Black Sea ports in the second period, commodities are stored in Moldova to be exported from Romanian Black Sea ports in the second period. Production and storage in the first period and transport in the second period are preferred since the war has affected transportation costs.

- In Example 4, with the initiative in place in the second period and the transport of commodities via Ukrainian Black Sea ports facilitated, all the wheat and corn harvests in the first period are stored inside Ukraine and in Moldova to be carried to the second period.

Insights and Summary

• The examples shed light on the importance of efficient maritime transportation of grains from the Black Sea ports of Ukraine, and the consequences of war in terms of the production and storage of agricultural commodities.

• The results reveal the impacts in terms of the significantly decreasing earnings of Ukrainian farmers and the increasing consumer prices.

• The examples indicate that, as a result of the ongoing war, Lebanon and Egypt are now essentially competing over the severely limited production, transportation, and storage capacity of Ukraine.

• The results show the priority of wheat over corn in both country demand markets since wheat is an essential part of most staple foods in MENA countries.

• One of the examples highlights the importance of keeping maritime routes from Ukraine for export of agricultural products operational.

Future Research

Future research can include:

- Adding exchange rates.
- Adding uncertainties associated with supplies and capacities as well as costs.
- Including nonagricultural commodities and impacts on transportation capacities.
- Incorporating quality of the agricultural commodities over time and associated demand.

Thank You!


The Virtual Center for Supernetworks
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Supernetworks for Optimal Decision-Making and Improving the Global Quality of Life
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The Virtual Center for Supernetworks is an interdisciplinary center at the Isenberg School of Management that advances knowledge on large-scale networks and integrates operations research and management science, engineering, and economics. Its Director is Dr. Anna Nagurney, the Eugene M. Isenberg Chair in Integrative Studies.
Mission: The Virtual Center for Supernetworks fosters the study and application of supernetworks and serves as a resource on networks ranging from transportation and logistics, including supply chains, and the Internet, to a spectrum of economic networks.
The Applications of Supernetworks Include: decision-making, optimization, and game theory; supply chain management; critical infrastructure from transportation to electric power networks; financial networks; knowledge and social networks; energy, the environment, and sustainability; cybersecurity; Future Internet Architectures; risk management; network vulnerability, resiliency, and performance metrics; humanitarian logistics and healthcare.
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