Agricultural Supply Chain Networks: From Trade to Resilience

Professor Anna Nagurney

Eugene M. Isenberg Chair in Integrative Studies
Director – Virtual Center for Supernetworks
Isenberg School of Management
University of Massachusetts Amherst

Enterprise-wide Optimization (EWO) Seminar Series
November 1, 2023
Department of Chemical Engineering, CMU, Pittsburgh, PA

ISENBERG
UMASS AMHERST

Acknowledgments

I'd like to thank Professor Chrysanthos Gounaris for the invitation to present in the EWO Series.

Special acknowledgments and thanks to my students and collaborators who have made research and teaching always stimulating and rewarding.

Outline of This Presentation

- **Background and Motivation**
- **Food Supply Chains and Disruptions**
- **International Agricultural Trade and Disasters**
- **Trade Policies and Exchange Rates**
- **The Multicommodity International Trade Model**
- **Making a Positive Impact**

Background and Motivation

I Work on the Modeling of Network Systems

Much of My Recent Research Has Been on Supply Chains

Some of My Books

International Trade

International trade provides us with commodities throughout the year and has benefits for producers and consumers alike.

Supply Chains Are Essential to Global Trade

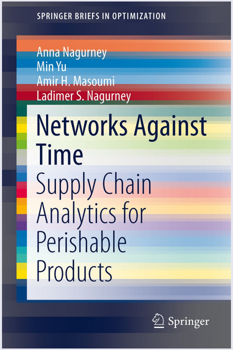
- **Global supply chain networks** have made possible the wide distribution of goods, from agricultural products to textiles and apparel as well as aluminum and steel.
- Nations engage in trade to increase their productivity levels, employment rates, and general economic welfare.
- The increased level of world trade has also garnered **the attention of government policy makers**.
- Governments may attempt to protect their domestic firms from the possible effects of the **highly competitive** global arena.

International Agricultural Trade

International agricultural trade provides us with essential agri-food commodities throughout the year, ensuring our food security and simultaneously benefiting the farmers.

A Multidisciplinary Approach

In our research on perishable and time-sensitive product supply chains, we utilize results from physics, chemistry, biology, and medicine in order to capture the perishability of various products over time from healthcare products such as blood, medical nucleotides, and pharmaceuticals to food.



Food Supply Chains and Disruptions

Food Supply Chains

Food is essential to our health and well-being. During the Covid-19 pandemic, declared on March 11, 2020 by the World Health Organization, the associated supply chains suffered major disruptions. Various disruptions continue because of climate change, Russia's war on Ukraine, and other disasters.

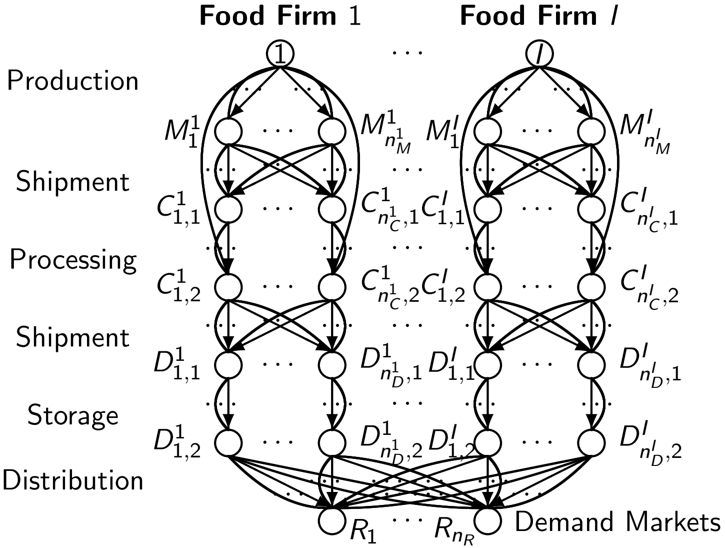
Fresh Produce Food Supply Chains

Our fresh produce supply chain network oligopoly model:

1. captures the deterioration of fresh food along the entire supply chain from a network perspective;
2. handles the time decay through the introduction of arc multipliers;
3. formulates oligopolistic competition with product differentiation;
4. includes the disposal of the spoiled food products, along with the associated costs;
5. allows for the assessment of alternative technologies involved in each supply chain activity.

M. Yu and A. Nagurney, "Competitive Food Supply Chain Networks with Application to Fresh Produce," *European Journal of Operational Research* **224(2) (2013), pp 273-282.**

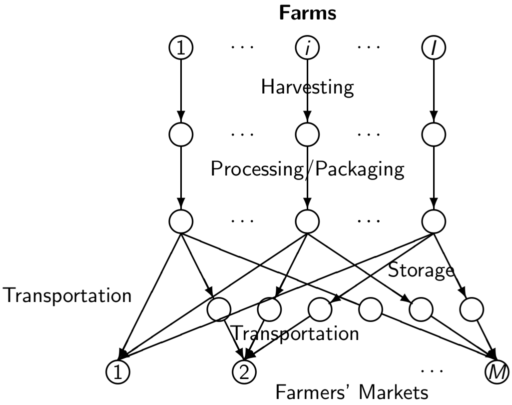
Fresh Produce Food Supply Chains

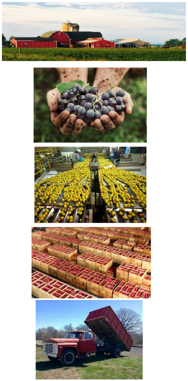


The Fresh Produce Supply Chain Network Topology

Farmers' Markets and Fresh Produce Supply Chains

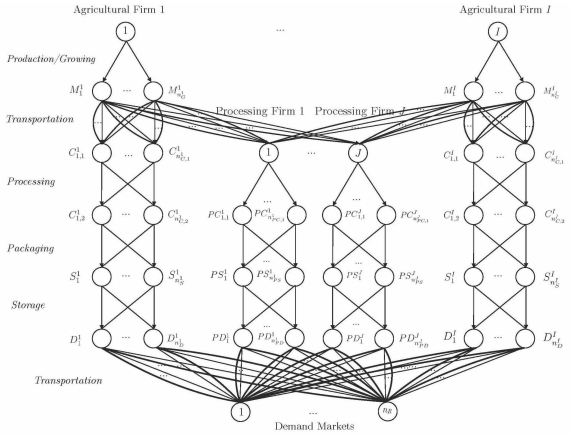
- The I farms compete **noncooperatively** in an **oligopolistic** manner.
- Products are differentiated based on **quality** at the farmers' markets.





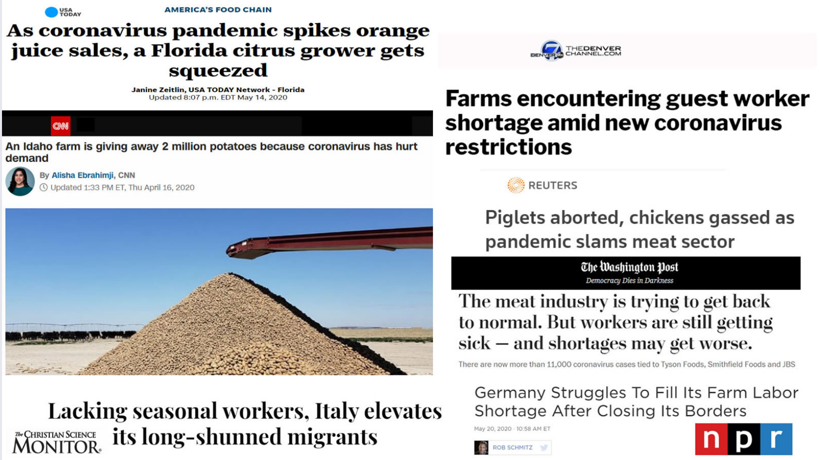
D. Besik and A. Nagurney, "Quality in Competitive Fresh Produce Supply Chains with Application to Farmers' Markets," *Socio-Economic Planning Sciences* **60 (2017), pp 62-76.**

Integrated Supply Chain Network Model



D. Besik, A. Nagurney, and P. Dutta, "An Integrated Multitiered Supply Chain Network Model of Competing Agricultural Firms and Processing Firms: The Case of Fresh Produce and Quality," *European Journal of Operational Research* **307(1) (2023), pp 364-381.**

Food Supply Chain Disruptions Due to COVID-19


USA TODAY

AMERICA'S FOOD CHAIN

As coronavirus pandemic spikes orange juice sales, a Florida citrus grower gets squeezed

Janine Zeitlin, USA TODAY Network - Florida
Updated 8:07 p.m. EDT May 14, 2020

CNN

An Idaho farm is giving away 2 million potatoes because coronavirus has hurt demand

By Alisha Ebrahimji, CNN
Updated 1:33 PM ET, Thu April 16, 2020

THEDENVERCHANNEL.COM

Farms encountering guest worker shortage amid new coronavirus restrictions

REUTERS

Piglets aborted, chickens gassed as pandemic slams meat sector

The Washington Post
Democracy Dies in Darkness

The meat industry is trying to get back to normal. But workers are still getting sick — and shortages may get worse.

There are now more than 11,000 coronavirus cases tied to Tyson Foods, Smithfield Foods and JBS

Germany Struggles To Fill Its Farm Labor Shortage After Closing Its Borders

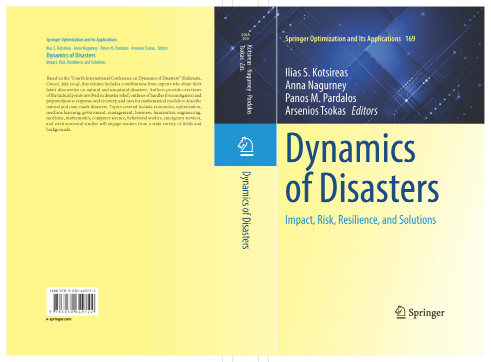
May 20, 2020 · 10:58 AM ET
ROB SCHMITZ
npr

The Christian Science Monitor

Lacking seasonal workers, Italy elevates its long-shunned migrants

Perishable Food Supply Chain Network Model with Labor

"Perishable Food Supply Chain Networks with Labor in the Covid-19 Pandemic," A. Nagurney, in: *Dynamics of Disasters - Impact, Risk, Resilience, and Solutions*, **I.S. Kotsireas, A. Nagurney, P.M. Pardalos, and A. Tsokas, Editors, Springer Nature Switzerland AG, 2021, pp 173-193.**



- **With lack of availability of labor being one of the drivers of supply chain disruptions**, the model considers labor in all the supply chain network economic activities of production, transportation, processing, storage, and distribution, while retaining perishability.

- **There are bounds on labor availability on each link as well as a productivity factor relating product flow to labor**.

- **Impacts of the reduction of labor (capacities) on supply chain network links** can then be quantitatively evaluated on the perishable product flows, the prices that the consumers pay, and profits of the firm.

- The framework enables a variety of sensitivity analysis exercises.

Our findings include:

1. **The lack of labor on a single link, even a freight one, may significantly negatively impact a food firm.**
2. **Preserving productivity in all utilized supply chain network economic activities is critical** since the impact of a drastic reduction can severely reduce profits.
3. **Adding more direct sales, whether at farmers' markets or nearby farm stands, may help a food firm in a pandemic.**
4. Also, if a firm **enhances its marketing** so as to have consumers be willing to pay a higher price for its fresh produce, **major profit increases can occur**.

Game Theory Supply Chain Network Modeling with Labor

In **"Supply Chain Game Theory Network Modeling Under Labor Constraints: Applications to the Covid-19 Pandemic," A. Nagurney,** *European Journal of Operational Research* **293(3), (2021), pp 880-891**, a game theory model for supply chains with labor was constructed, under three different sets of constraints, building on our previous work.

European Journal of Operational Research 293 (2021) 880–891

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing, Transportation and Logistics

Supply chain game theory network modeling under labor constraints: Applications to the Covid-19 pandemic

Anna Nagurney

Department of Operations and Information Management, Isenberg School of Management, University of Massachusetts, Amherst, MA 01003, USA

ARTICLE INFO

Article history:
Received 17 August 2020
Accepted 23 December 2020
Available online 3 January 2021

Keywords:
Supply chain management
Labor
Game theory
Pandemic
Variational inequalities

ABSTRACT

The Covid-19 pandemic has brought attention to supply chain networks due to disruptions for many reasons, including that of labor shortages as a consequences of illnesses, death, risk mitigation, as well as travel restrictions. Many sectors of the economy from food to healthcare have been competing for workers, as a consequence. In this paper, we construct a supply chain game theory network framework that captures labor constraints under three different scenarios. The appropriate equilibrium constructs are defined, along with their variational inequality formulations. Computed solutions to numerical examples inspired by shortages of migrant labor to harvest fresh produce; specifically, blueberries, in the United States, reveal the impacts of a spectrum of disruptions to labor on the product flows and the profits of the firms in the supply chain network economy. This research adds to the literature in both economics and operations research.

1. Introduction

The Covid-19 pandemic, officially declared by the World Health Organization on March 11, 2020, has demonstrated dramatically the importance of the health of workers to the global economy (Organization, 2020). Product supply chains as varied as those for Personal Protective Equipment (PPEs) (Burki, 2020) and other medical supplies (Ranney, Griffieth, & Jha, 2020), toilet paper and cleaning supplies (Gao, 2020), meat (Corkery & Yaffe-Bellany, 2020) and fresh produce (Knight, 2020; Laborde, Martin, Swinnen, & Vos, 2020), and even blood (Nagurney, 2020a), have been disrupted for reasons including that of the reduction of labor availability because of illnesses and death of workers, along with workers' fear of contracting the disease. Some workers have not been able to travel for seasonal employment because of travel restrictions to mitigate the spread of the coronavirus that causes the Covid-19 disease, resulting in both economic and personal losses (IHS-Markit, 2020). According to Elflein (2020), as of August 14, 2020, Covid-19 had spread to six continents, with over 750,000 succumbing to the coronavirus that causes the Covid-19 disease. Just over 2 months after, as of October 27, 2020, there were 1,160,421 documented deaths globally due to Covid-19 (JHU-CSSE2020, 2020). The negative impact of this global healthcare and economic crisis has affected different tiers of supply chains and associated network economic activities of production, transportation, storage, and distribution.

Labor has emerged as an essential factor in the functioning of supply chains in the pandemic. Without farmers, food cannot be produced. Without workers to harvest, food may end up rotting in the fields or be discarded (see Associated Press, 2020); without freight service provision food cannot be delivered to food processors; without food processors food cannot be processed, resulting in additional waste (see Polansek & Huffstutter, 2020). Ultimately, freight service provision is also essential for deliveries to retail outlets for purchase by consumers or even for direct transport to consumers using, for example, electronic commerce. Freight service workers have also been impacted by Covid-19 (Parker, 2020). Employees at distribution centers have been felled by Covid-19 (Daniels, 2020), as well, and Covid-19 has further exacerbated worker shortages at a time of greater demand because of electronic commerce (see Hardwick, 2020). Shortages of labor in manufacturing facilities were an issue even earlier on in February 2020 in China, since that country was impacted first by the coronavirus, which was to have originated in Wuhan, with implications for global supply chains (see Bloomberg, 2020). Labor shortages arose due to illnesses, need for social distancing in facilities, as well as adherence to quarantines. Each link of a product supply chain requires labor, and, therefore, reduction in labor capacity can propagate through paths of a supply chain network, affecting product flows as well as prices (see, e.g., OECD, 2020). Furthermore, unhealthy workers cannot be fully productive.

E-mail address: nagurney@isenberg.umass.edu

https://doi.org/10.1016/j.ejor.2020.12.054

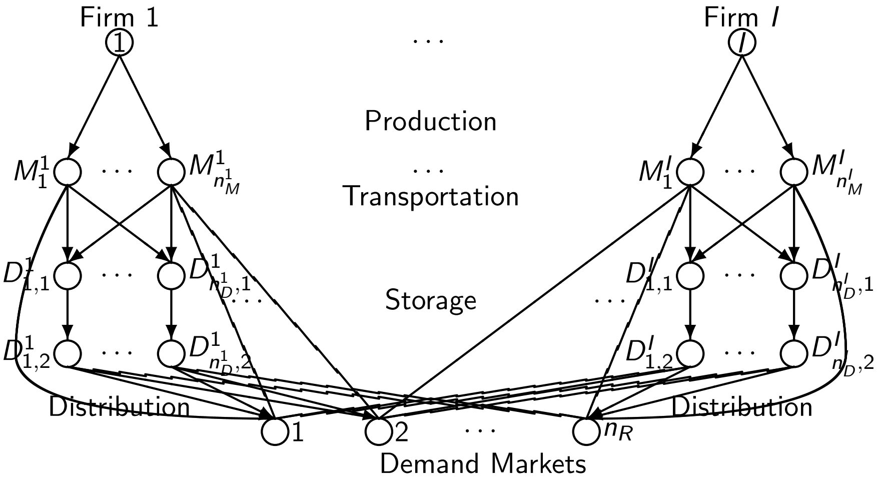


Figure: The Supply Chain Network Topology of the Game Theory Model with Labor

Numerical Experiments

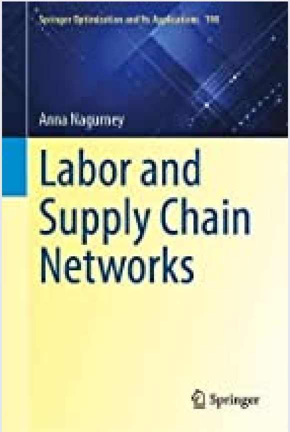
Our numerical examples are based on disruptions in migrant labor in the blueberry supply chain in the Northeast of the US in the summer of 2020.

- Disruptions in labor on a supply chain network link;
- Addition of a competitor;
- Modifications in demand price functions;
- Sensitivity analysis in terms of labor availability.

The full input and out data are available in our paper in the *European Journal of Operational Research.*

Farmers should do everything possible to secure the health of the workers at his production/harvesting facilities, so that the blueberries can be harvested in a timely manner and so that profits do not suffer. Keeping workers healthy, through appropriate measures, impacts the bottom line!

New Book



International Agricultural Trade and Disasters

International Agricultural Trade and Disasters

- **Our planet and people are being faced with immense challenges brought about by disasters, including man-made ones.**
- **Disasters can have an immense impact on nations, regions, businesses, organizations, and individuals. A multiplicity of disasters can also impact food security.**

- **Climate change and COVID-19 impacted the affordability and accessibility of agri-food products around the globe.**
- **With the added disruptions of Russia's full-scale invasion of Ukraine, around 47 million people are estimated to have been added to the more than 276 million who were already facing food insecurity.**

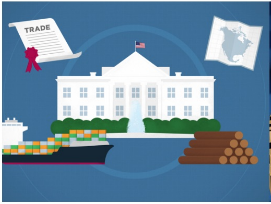
Disasters and Food Security

- The FAO of the United Nations reports that between 20 and 30 percent of the Ukrainian land previously used for cultivating winter crops will probably remain unsown due to the ongoing war.
- In addition, there have been immense challenges in getting the exports of agricultural products out of Ukraine with the blockade of the Black Sea in wartime and various bottlenecks.

Trade Policies and Exchange Rates

International Trade and Policies

- **Nations engage in trade to increase their productivity levels, employment rates, and general economic welfare.**
- **The increased level of world trade and competition has garnered the attention of government policy makers.**
- Trade policy instruments such as tariffs, subsidies, and quotas have become highly relevant as the world continues to battle the impacts of the COVID-19 pandemic and millions on the planet suffer from hunger and growing food insecurity.



Global Trade Policies

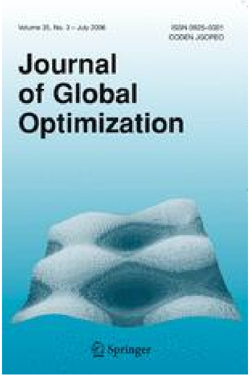
Examples of policy instruments that have been applied by governments to modify trade patterns included: **tariffs**, **quotas**, and a combination thereof - **tariff rate quotas**.

- A tariff rate quota (TRQ) is a **two-tiered tariff**, in which a lower **in-quota tariff** is applied to imports until a quota is attained and then a higher **over-quota tariff** is applied to all subsequent imports.
- The Uruguay Round in 1996 induced the creation of more than 1,300 new TRQs.
- **The world's four most important food crops: rice, wheat, corn, and bananas have all been subject to tariff rate quotas.**

Global Trade Policies

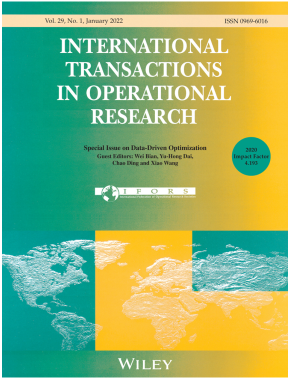
We have been constructing **computable operational mathematical models** that enable the assessment of the impacts of trade policy instruments such as tariffs, quotas, and also tariff rate quotas on consumer prices, trade flows, as well as on the profits of producers/firms.

A. Nagurney, D. Besik, and L.S. Nagurney, "Global Supply Chain Networks and Tariff Rate Quotas: Equilibrium Analysis with Application to Agricultural Products, *Journal of Global Optimization* **75 (2019), pp 439-460.**

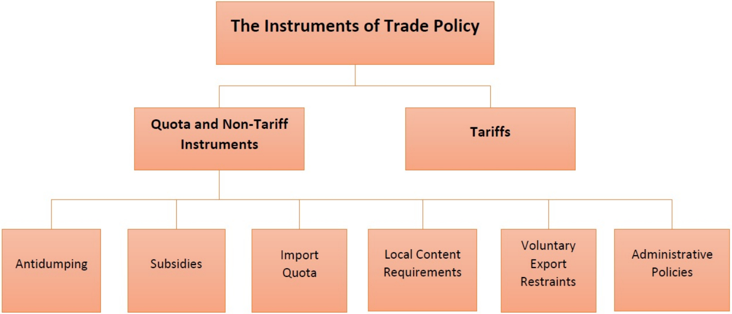


A. Nagurney, D. Besik, and J. Dong, "Tariffs and Quotas in World Trade: A Unified Variational Inequality Framework," *European Journal of Operational Research* **275(1) (2019), pp 347-360.**

A. Nagurney, M. Salarpour, and J. Dong, "Modeling of Covid-19 Trade Measures on Essential Products: A Multiproduct, Multicountry Spatial Price Equilibrium Framework," *International Transactions in Operational Research* **29(1) (2022), pp 226-258.**

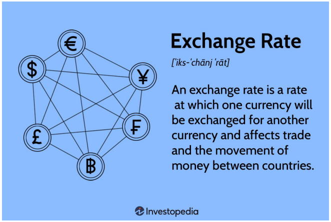


Identifying quantitatively the **impacts of trade policies and exchange rates** on international trade can provide trade and regulatory bodies with valuable information on product trade volumes and producer and consumer prices.



Exchange Rates

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.

Exchange Rates

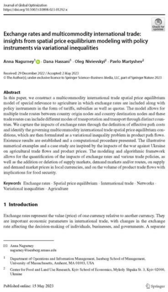
- The US dollar has gotten stronger over the past year, with the greatest rate of increase occurring since the Russian invasion of Ukraine on February 24, 2022, with the war still ongoing.

- In contrast, during the first year of the COVID-19 pandemic, the dollar weakened with respect to the euro, the British pound, and the yen.

The Multicommodity International Trade Model

A Model, Hot Off the Press

A. Nagurney, D. Hassani, O. Nivievskyi, and P. Martyshev, "Exchange Rates and Multicommodity International Trade: Insights from Spatial Price Equilibrium Modeling with Policy Instruments via Variational Inequalities," *Journal of Global Optimization* **87 (2023), pp 1-30.**



Journal of Global Optimization
https://doi.org/10.1007/s10898-023-01292-x

Check for updates

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

✉ Anna Nagurney
nagurney@isenberg.umass.edu

1 Department of Operations and Information Management, Isenberg School of Management, University of Massachusetts, Amherst, MA 01003, USA

2 Center for Food and Land Use Research, Kyiv School of Economics, Mykoly Shpaka St. 3, Kyiv 02000, Ukraine

Published online: 15 May 2023

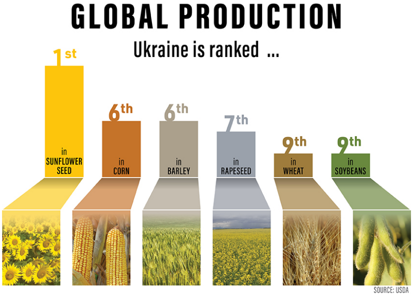
Springer

In this paper, we harness the powerful theory of variational inequalities to construct a model with the following features:

- **Multiple commodities**;
- **Multiple routes from origin nodes to destination nodes** in the same or different countries;
- **Exchange rates** and the formula for their computation along trade routes;
- Inclusion of policies in the form of **tariffs, subsidies, and quotas**;
- The underlying **economic functions can be nonlinear and asymmetric**. Hence, our **transportation cost functions capture congestion**.

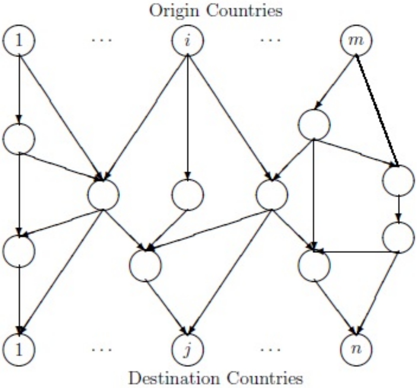
Additional Motivation

This work is inspired by Russia's war on Ukraine and the need to assess its impacts on agricultural trade as well as on food insecurity and the need to provide more general computable models for assessing the impacts of trade policies and exchange rates on international trade.



An Acknowledgment

The authors acknowledge the partnership established between the University of Massachusetts Amherst and the Kyiv School of Economics, which provided support for this collaboration.



The network topology is denoted by the graph $G = [N, L]$, where N is the set of nodes, L is the set of links, and P is the set of paths. There are H commodities, with a typical one denoted by h.

The Multicommodity International Trade Model

Each path p represents a trade route. Intermediate nodes in the network, which are transit points, also correspond to countries.

Let P_{ij} denote the set of paths connecting the pair of origin/destination country nodes (i, j). The paths are acyclic.

A typical link is denoted by a and represents transport from a country node at which the link originates to the node denoting the country at which the link terminates.

A trade route can entail transportation through multiple countries, depending on the application, and via different modes, such as rail, truck, air, or water (sea, river, etc.).

The Exchange Rates

Associated with each link $a \in L$ is an exchange rate e_a, reflecting the exchange rate from the country (node) that the link emanates from to the country (node) that it terminates in.

Also, associated with each pair of origin/destination countries (i,j) is the exchange rate e_{ij} for $i = 1, \ldots, m$; $j = 1, \ldots, n$.

There is a nonnegative subsidy associated with commodity h and imposed by the government in country i, which is denoted by sub_i^h for $h = 1, \ldots, H$; $i = 1, \ldots, m$.

The unit tariff levied by country j on commodity h from country i is denoted by τ_{ij}^h for $h = 1, \ldots, H$; $i = 1, \ldots, m$; $j = 1, \ldots, n$. Tariffs within a country are not imposed; hence, $\tau_{ii}^h = 0$, $\forall i$, $\forall h$.

In addition, there are capacities, which can represent quotas, where $\bar{Q}_p^h$; $h = 1, \ldots, H$; $p \in P$, denotes the bound on the commodity shipment of commodity h on path p.

Variables and Constraints

All commodity path flows, for all commodities h, and all paths p, must be nonnegative:

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

The flow on a link a of commodity h, in turn, is equal to the sum of the path flows of the commodity h that use the link:

$$f_a^h = \sum_{p \in P} Q_p^h \delta_{ap}, \quad \forall h, \forall a \in L. \tag{2}$$

where $\delta_{ap} = 1$, if link a is contained in path p, and is 0, otherwise.

Variables and Constraints

The supply of commodity h produced in country i, s_i^h, is equal to the shipments of the commodity from the country to all destination countries:

$$s_i^h = \sum_{p \in P^i} Q_p^h, \quad h = 1, \ldots, H; i = 1, \ldots, m, \tag{3}$$

whereas the demand for commodity h in country j, d_j^h, is equal to the shipments of the commodity from all origin countries to that country:

$$d_j^h = \sum_{p \in P_j} Q_p^h, \quad h = 1, \ldots, H; j = 1, \ldots, n. \tag{4}$$

$Q \in R_+^{n_P}$ is the vector of commodity shipments with $s \in R_+^{Hm}$ being the vector of commodity supplies and $d \in R_+^{Hn}$ being the vector of commodity demands.

Supply Price Functions

The supply price function for commodity h of country i is denoted by π_i^h and we have that:

$$\pi_i^h = \pi_i^h(s), \quad h = 1, \ldots, H; i = 1, \ldots, m. \tag{5a}$$

With notice of the conservation of flow equations (3), we may define new supply price functions $\tilde{\pi}_i^h$; $h = 1, \ldots, H$; $i = 1, \ldots, m$, such that

$$\tilde{\pi}_i^h(Q) \equiv \pi_i^h(s). \tag{5b}$$

Demand Price Functions

The demand price functions, in turn, are:

$$\rho_j^h = \rho_j^h(d), \quad h = 1, \ldots, H; j = 1, \ldots, n, \tag{6a}$$

where ρ_j^h denotes the demand price for commodity h in country j. Making use now of conservation of flow equations (4), we construct equivalent demand price functions $\tilde{\rho}_j^h$; $h = 1, \ldots, H$; $j = 1, \ldots, n$, as follows:

$$\tilde{\rho}_j^h(Q) \equiv \rho_j^h(d). \tag{6b}$$

.

Transportation Cost Functions

With each link $a \in L$, and commodity h, we associate a unit transportation cost c_a^h such that

$$c_a^h = c_a^h(f), \quad \forall h, \forall a \in L. \tag{7a}$$

Because of the conservation of flow equations (2), we can define link unit transportation cost functions $\tilde{c}_a^h(Q)$, $\forall a \in L$, $\forall h$, as:

$$\tilde{c}_a^h(Q) \equiv c_a^h(f). \tag{7b}$$

The Effective Exchange Rate

Observe that, in order to appropriately quantify the effective transportation cost on a link a for a commodity h, if a commodity makes use of the link on a path from an origin country node to a destination country node, one needs to calculate the effective exchange rate associated with the commodity on link a being transported onward on path p, which is denoted by e_a^p. Note that e_a^p is the product of the exchange rates on the links on path p that include and follow link a on that path, and is given by:

$$e_a^p \equiv \begin{cases} \prod_{b \in \{a' \geq a\}_p} e_b, & \text{if } \{a' \geq a\}_p \neq \emptyset, \\ 0, & \text{if } \{a' \geq a\}_p = \emptyset, \end{cases} \tag{8}$$

where $\{a' \geq a\}_p$ denotes the set of the links including and following link a in path p, and $\emptyset$ denotes the null set.

The Effective Transportation Cost

The true transportation cost then on link a, $a \in L$, for commodity h; $h = 1, \ldots, H$, when it is used in a path p, is given by the expression:

$$\tilde{c}_a^{hp} = \tilde{c}_a^h(Q) e_a^p. \tag{9}$$

The effective transportation cost on a path, $\tilde{C}_p^h$, $\forall p \in P$, for commodity h; $h = 1, \ldots, H$, is then calculated as:

$$\tilde{C}_p^h = \sum_{a \in L} \tilde{c}_a^{hp} \delta_{ap}; \tag{10}$$

that is, the effective transportation cost on a path, which represents a trade route, is equal to the sum of the effective transportation costs for the commodity on links that make up the path.

Equilibrium Conditions

Definition 1: The Multicommodity International Trade Equilibrium Conditions

A multicommodity path trade flow pattern $Q^* \in R_+^{n_P}$ is an international trade spatial price network equilibrium pattern under subsidies and tariffs with explicit exchange rates and capacities if the following conditions hold: For all pairs of country origin and destination nodes: (i,j); $i = 1, \ldots, m$; $j = 1, \ldots, n$, and all paths $p \in P_{ij}$ as well as all commodities h; $h = 1, \ldots, H$:

$$(\tilde{\pi}_i^h(Q^*) - sub_i^h + \tau_{ij}^h)e_{ij} + \tilde{C}_p^h(Q^*) \begin{cases} \leq \tilde{\rho}_j^h(Q^*), & \text{if} \quad Q_p^{h*} = \bar{Q}_p^h, \\ = \tilde{\rho}_j^h(Q^*), & \text{if} \quad 0 < Q_p^{h*} < \bar{Q}_p^h, \\ \geq \tilde{\rho}_j^h(Q^*), & \text{if} \quad Q_p^{h*} = 0. \end{cases} \tag{11}$$

Variational Inequality Formulation and Existence

Theorem 1: Variational Inequality Formulation of the Multicommodity International Trade Equilibrium Conditions

A multicommodity path trade flow pattern $Q^* \in K$, where $K \equiv \{Q|0 \leq Q \leq \bar{Q}\}$ is a multicommodity international trade spatial price network equilibrium pattern with exchange rates and under subsidies and tariffs and capacities, according to Definition 1, if and only if it satisfies the variational inequality:

$$\sum_{h=1}^{H} \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{p \in P_{ij}} \left[(\tilde{\pi}_i^h(Q^*) - sub_i^h + \tau_{ij}^h) e_{ij} + \tilde{C}_p^h(Q^*) - \tilde{\rho}_j^h(Q^*) \right]$$

$$\times \left[Q_p^h - Q_p^{h*} \right] \geq 0, \quad \forall Q \in K. \tag{12}$$

Existence of an equilibrium solution Q^* is guaranteed since the feasible set K is compact.

Standard Form

Variational inequality (12) is now put into standard form (cf. Nagurney (1999)), VI$(F, \mathcal{K})$, where one seeks to determine a vector $X^* \in \mathcal{K} \subset R^{\mathcal{N}}$, such that

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K}, \tag{13}$$

where F is a given continuous function from $\mathcal{K}$ to $R^{\mathcal{N}}$, $\mathcal{K}$ is a given closed, convex set, and $\langle \cdot, \cdot \rangle$ denotes the inner product in $\mathcal{N}$-dimensional Euclidean space.

Specifically, we define $X \equiv Q$, $\mathcal{K} \equiv K$, and $\mathcal{N} = Hn_P$. Plus, $F(X)$ consists of the elements

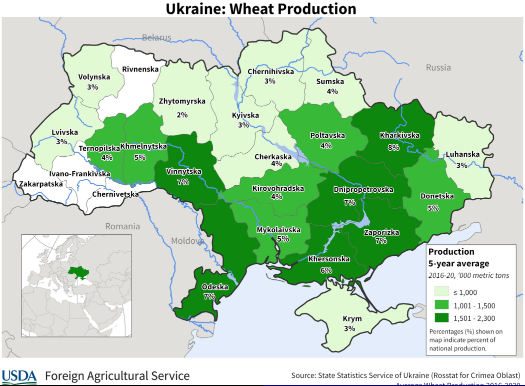
$F_p^h(X) \equiv \left[(\tilde{\pi}_i^h(Q) - sub_i^h + \tau_{ij}^h) e_{ij} + \tilde{C}_p^h(Q) - \tilde{\rho}_j^h(Q) \right]$, $\forall h$, $\forall i, j$, $\forall p \in P_{ij}$. Clearly, VI (12) can be put into standard form (13).

Illustrative Examples

Illustrative Examples

The examples focus on wheat commodity flows from Ukraine to Lebanon before and after the invasion of Ukraine by Russia on February 24, 2022.

The local currency codes are: UAH for Ukrainian hryvnia, MDL for the Moldovan leu, RON for the Romanian leu, LBP for the Lebanese pound, and USD for the United States dollar.



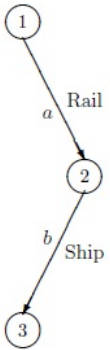
Illustrative Examples

The unit of flow is a ton of wheat.

In these examples, there are no commodity path flow capacities.

These illustrative examples are stylized but, nevertheless, are grounded in real data.

Example 1 - Pre-Invasion Scenario



The network topology for Illustrative Example 1 with nodes 1 and 2 representing Ukraine and node 3 corresponding to Lebanon. There is a single path $p_1 = (a, b)$, where link a corresponds to transport to the Black Sea ports via rail inside Ukraine, and link b represents maritime transport from the Black Sea ports to Lebanon.

Example 1 - Pre-Invasion Scenario

The exchange rate data for Example 1 is drawn from early January 2022:

$$e_{13} = 55.0581, \quad e_a = 1.0000, \quad e_b = 55.0581.$$

The supply price function in Ukraine in hryvnia is:

$$\pi_1 = \pi_1(s_1) = .000136 s_1 + 7,001.60.$$

The transportation cost functions in local currencies are:

$$c_a = c_a(f_a) = .000278 f_a + 954.80, \quad c_b = c_b(f_b) = .000278 f_b + 1,091.20.$$

The demand price function in Lebanon in Lebanese pounds is:

$$\rho_3 = \rho_3(d_3) = -.15 d_3 + 602,344.00.$$

The effective exchange rates and the effective link costs are:

$$e_a^{p_1} = e_a e_b = 55.0581, \quad e_b^{p_1} = 55.0581,$$

$$\tilde{c}_a^{p_1} = e_a^{p_1} \tilde{c}_a = 55.0581 \tilde{c}_a, \quad \tilde{c}_b^{p_1} = e_b^{p_1} \tilde{c}_b = 55.0581 \tilde{c}_b.$$

Example 1 - Pre-Invasion Scenario

The effective path cost on path p_1 is:

$$\tilde{C}_{p_1} = \tilde{c}_a^{p_1} + \tilde{c}_b^{p_1}.$$

Applying the international trade spatial price equilibrium conditions (11), under the assumption of no tariff and no subsidy, and no quota, and assuming that $Q^*_{p_1} > 0$, we have that:

$$\tilde{\pi}_1(Q^*_{p_1})e_{13} + \tilde{C}_{p_1}(Q^*_{p_1}) = \tilde{\rho}_3(Q^*_{p_1}),$$

which, in turn, reduces to:

$$.1881 Q^*_{p_1} = 104,200.3344,$$

with solution:

$$Q^*_{p_1} = 553,962.4370.$$

The $553,962.4370$ tons of wheat flow is quite reasonable, since, in 2021, Lebanon imported $520,000$ tons of wheat from Ukraine, and an even greater harvest was expected in 2022.

Example 1 - Pre-Invasion Scenario

The above wheat commodity flow pattern results in a supply and a demand of:

$$s_1^* = d_3^* = Q_{p_1}^* = 553,962.4370.$$

The supply and demand prices are:

$$\pi_1(s_1^*) = \tilde{\pi}_1(Q_{p_1}^*) = 7,076.9388 \text{ UAH} = \$257.7002,$$

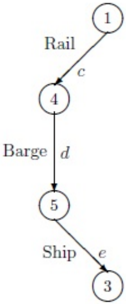
$$\rho_3(d_3^*) = \tilde{\rho}_3(Q_{p_1}^*) = 519,249.6344 \text{ LBP} = \$343.4190.$$

The incurred transportation costs are:

$$\tilde{c}_a = 1,108.8015 \text{ UAH} = \$40.3759, \quad \tilde{c}_b = 1,245.2015 \text{ UAH} = \$45.3428.$$

The supply price of $\$257.7002$ per ton of wheat in Ukraine (at the farmer level) and the demand price of $\$343.4190$ in Lebanon are close to the reported prices in 2021. Farmers in Ukraine could get about $\$270$ per ton of wheat before the invasion. The transportation cost pre-invasion for a ton of wheat in Ukraine to a port was about $\$40$, as is the result in this example.

Example 2 - Invasion Scenario



In Example 2, we consider the invasion scenario after February 24, 2022, but before the Black Sea Grain Initiative, which took effect in late July. During this period, essentially no grain was shipped from Ukraine using a Black Sea route as in Example 1. There is a single path $p_2 = (c, d, e)$. Nodes 1, 3, 4, and 5 denote Ukraine, Lebanon, Moldova, and Romania, respectively.

Example 2 - Invasion Scenario

The exchange rates for Example 2 are obtained from early July; that is, after the invasion but before the Black Sea Grain Initiative:

$$e_{13} = 51.6836, \quad e_c = .6528, \quad e_d = .2523, \quad e_e = 313.6980,$$

The exchange rates were essentially the same on July 20, 2022.

The supply price function in Ukraine in hryvnia is:

$$\pi_1(s) = \pi_1(s_1) = .002673s_1 + 2,806.30.$$

The difference in supply price function compared to the function in Example 1 is due to the damages because of the war.

Example 2 - Invasion Scenario

The transportation cost functions in local currencies are:

$$c_c = .002768 f_c + 6,546.50, \quad c_d = .002172 f_d + 2,324.60, \quad c_e = .000257 f_e + 345.40.$$

The difference in the cost function on link c in this example and the cost function on link a in Example 1, with both entailing rail transportation in Ukraine, is due to the different rail gauges used in Ukraine and Moldova, which necessitates including loading and unloading costs. Loading and unloading costs are also accounted for in the cost function on link d.

The demand price function in Lebanon in Lebanese pounds is:

$$\rho_3(d) = \rho_3(d_3) = -.17 d_3 + 793,747.50.$$

Note that due to the food security issues in Lebanon and concerns over the availability of Ukrainian wheat because of the war, the demand price function is different from the one in Example 1.

Example 2 - Invasion Scenario

According to the international trade spatial price equilibrium conditions (11), and assuming that $Q^*_{p_2} > 0$, we have that:

$$\tilde{\pi}_1(Q^*_{p_2})e_{13} + \tilde{C}_{p_2}(Q^*_{p_2}) = \tilde{\rho}_3(Q^*_{p_2}),$$

the solution of which yields:

$$Q^*_{p_2} = 25,780.2589.$$

The wheat flow of $25,780.2589$ tons is reasonable since, without access to deep-sea ports on the Black Sea, Ukraine can, at most, export around 10% of what it used to.

This commodity flow results in a supply and a demand of:

$$s^*_1 = d^*_3 = Q^*_{p_2} = 25,780.2589.$$

Example 2 - Invasion Scenario

The supply and demand prices are:

$$\pi_1(s_1^*) = \tilde{\pi}_1(Q^*) = 2,875.2106 \text{ UAH} = \$98.2813,$$

$$\rho_3(d_3^*) = \tilde{\rho}_3(Q^*) = 789,364.8559 \text{ LBP} = \$522.0667.$$

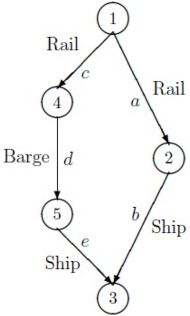
The incurred transportation link costs are:

$$\tilde{c}_c = 6,617.8597 \text{ UAH} = \$226.2137, \ \tilde{c}_d = 2,380.5947 \text{ MDL} = \$124.6358$$

$$\tilde{c}_e = 352.0255 \text{ RON} = \$73.0358.$$

The transportation cost of grain inside Ukraine has jumped to about \$200. **Furthermore, because of the ongoing war, Ukrainian farmers are earning approximately** \$100 **per ton of wheat, which is similar to the supply price of** \$98.2813 **in this example. Moreover, with the continuing food crisis in Lebanon, and, as a result of the war, the price of wheat in Lebanon has gone up to more than** \$500 **per ton.**

Example 3 - Black Sea Grain Initiative in Place



The network topology for Example 3, where we consider the post-July 22 Black Sea Grain Initiative scenario with maritime transportation from several of the Ukrainian Black Sea ports being, again, possible. In the network above, the nodes and the links correspond to the same countries and modes of transportation as in Examples 1 and 2.

Example 3 - Black Sea Grain Initiative in Place

The exchange rates on links are from late August; that is, after the Black Sea Grain Initiative:

$$e_a = 1.0000, \quad e_b = 41.3469, \quad e_c = .5291,$$

$$e_d = .2521, \quad e_e = 309.8670, \quad e_{13} = 41.3469.$$

The exchange rates were essentially the same on July 22, 2022.

The supply price function in Ukrainian hryvnia is now:

$$\pi_1(s) = \pi_1(s_1) = .000167s_1 + 3,364.60.$$

Observe that due to the damages by the ongoing war, the supply price function, again, changes from the ones in Examples 1 and 2.

Example 3 - Black Sea Grain Initiative in Place

The transportation cost functions in local currencies are:

$$c_a = .000217 f_a + 7,144.80, \quad c_b = .000246 f_b + 7,423.10,$$

$$c_c = .003284 f_c + 8,304.80, \quad c_d = .003097 f_d + 2,397.50,$$

$$c_e = .000428 f_e + 361.20.$$

The damages to the transportation infrastructure, and the congestion associated with products to be exported after the placement of the Black Sea Grain Initiative, result in different transportation cost functions from the previous examples.

The demand price function in Lebanese pounds is:

$$\rho_3(d) = \rho_3(d_3) = -.082 d_3 + 796,162.50.$$

The demand price function is different from Example 2, which is in correspondence to the food security issues in Lebanon.

Example 3 - Black Sea Grain Initiative in Place

The equilibrium conditions (11) are, for this example, assuming positive commodity shipments:

$$\tilde{\pi}_1(Q^*)e_{13}+\tilde{C}_{p_1}(Q^*_{p_1}) = \tilde{\rho}_3(Q^*), \quad \tilde{\pi}_1(Q^*)e_{13}+\tilde{C}_{p_2}(Q^*_{p_2}) = \tilde{\rho}_3(Q^*).$$

The solution of the above system of equations yields a negative path flow on path p_2, which is infeasible. Therefore, path p_2 is not used. Then, one has that: $Q^*_{p_1} = 506,566.8120$ and $Q^*_{p_2} = 0.0000$, with the commodity flows, again, in tons.

The supply is similar to what Ukraine used to export to Lebanon pre-war. With the availability of maritime transportation from Ukraine on the Black Sea, the wheat flow on path p_2 is at 0.0000, which is due to the inefficiency of transporting the grain to a Middle Eastern country by such a route and composition of modes.

Example 3 - Black Sea Grain Initiative in Place

This wheat commodity flow pattern results in the following supply and demand:

$$s_1^* = d_3^* = Q_{p_1}^* + Q_{p_2}^* = 506,566.8120,$$

with the supply and demand prices per ton now being:

$$\pi_1(s_1^*) = \tilde{\pi}_1(Q^*) = 3,449.1966 \text{ UAH} = \$94.3212,$$

$$\rho_3(d_3^*) = \tilde{\rho}_3(Q^*) = 754,624.0214 \text{ LBP} = \$499.0899.$$

The incurred transportation costs are:

$$\tilde{c}_a = 7,254.7249 \text{ UAH} = \$198.3867, \quad \tilde{c}_b = 7,547.7154 \text{ UAH} = \$206.3988,$$

$$\tilde{c}_c = 8,304.8000 \text{ UAH} = \$227.1019, \quad \tilde{c}_d = 2,397.5000 \text{ MDL} = \$123.9018,$$

$$\tilde{c}_e = 361.2000 \text{ RON} = \$74.0245.$$

Although the initiative has facilitated the transportation of wheat, the war, and nearly full storage have kept the prices high. The supply price at \$94.3212 **and the demand price at** \$499.0899**, along with the** \$206.3988 **transportation cost on link** b**, reflect these issues and are preventing the demand**

Example 4 - Example 3 Data with Subsidy

In Example 4, we, again, consider the post-July 22 Black Sea Grain Initiative scenario with maritime transportation via the Black Sea from Ukraine possible; however, a subsidy is introduced in this example, and the impact is quantified. We consider the effect of the subsidy $sub_1 = 1,000.00$ in hryvnia on Ukrainian wheat shipped to Lebanon:

In the solution of this example, again, only path p_1 is used, and one has that: $Q^*_{p_1} = 889,408.4787$ and $Q^*_{p_2} = 0.0000$.

This wheat commodity flow pattern results in the following supply and demand:

$$s^*_1 = d^*_3 = Q^*_{p_1} + Q^*_{p_2} = 889,408.4787,$$

with the following supply and demand prices:

$$\pi_1(s^*_1) = \tilde{\pi}_1(Q^*) = 3,513.1312 \text{ UAH} = \$96.0696,$$

$$\rho_3(d^*_3) = \tilde{\rho}_3(Q^*) = 723,231.0047 \text{ LBP} = \$478.3273.$$

Example 4 - Example 3 Data with Subsidy

The incurred transportation costs are:

$$\tilde{c}_a = 7,337.8016 \text{ UAH} = \$200.6585, \ \tilde{c}_b = 7,641.8944 \text{ UAH} = \$208.9742,$$

$$\tilde{c}_c = 8,304.8000 \text{ UAH} = \$227.1019, \ \tilde{c}_d = 2,397.5000 \text{ MDL} = \$123.9018$$

$$\tilde{c}_e = 361.2000 \text{ RON} = \$74.0245.$$

The subsidy increases the quantity of wheat shipment, and increases the price that farmers can expect to get for a ton of wheat to \$96.0696**, which is of value as the current low supply prices threaten the farmers' ability to buy seed and equipment for the next harvest season.**

The subsidy also helps to reduce the demand price to \$478.3273**, which can be of significant importance in countering the food crisis and associated food insecurity in Lebanon.**

Insights

- **The importance of having alternative routes in countering disruptions and congestion** is evident in our examples.

- The results strongly confirm **the need for efficient transportation routes for trade**, as, for example, for the export of grain via maritime transport from the Black Sea ports in the case of Ukraine.

- The examples show the **benefits of subsidies for agricultural trade for both farmers and consumers**.

- **The impact of the exchange rates on the grain commodity flows and on producer and consumer prices are revealed** in the examples for different periods: pre-invasion, following the invasion, and after the Black Sea Grain Initiative.

- **The examples demonstrate the importance of the Ukrainian grain, and its relevance to global food security.**

Some Additional Research

A. Nagurney and E. Besedina, "A Multicommodity Spatial Price Equilibrium Model with Exchange Rate and Non-Tariff Measures," *Operations Research Forum* **4, Article number 84 (2023).**

A. Nagurney, "Food Security and Multicommodity Agricultural International Trade: Quantifying Optimal Consumer Subsidies for Nutritional Needs, " *International Transactions in Operations Research*, **(2023)**, in press.

A. Nagurney, D. Hassani, O. Nivievskyi, and P. Martyshev, "Quantification of International Trade Network Performance Under Disruptions to Supply, Transportation, and Demand Capacity, and Exchange Rates in Disasters, (2023), under review.

A. Nagurney, D. Hassani, O. Nivievskyi, and P. Martyshev, "Multicommodity International Agricultural Trade Network Equilibrium: Competition for Limited Production and Transportation Capacity under Disaster Scenarios with Implications for Food Security," (2023), under review.

Making a Positive Impact

Writing OpEds

THE CONVERSATION
Academic rigor, journalistic flair

Arts + Culture Economy + Business Education Environment + Energy Ethics + Religion Health + Medicine Politics + Society Science + Technology

How disaster relief efforts could be improved with game theory

March 9, 2017 11.21pm EST

Buddhist monks and family members of victims of the Fukushima tsunami and earthquake face the sea to pray on March 11, 2016 while mourning the victims of the March 11, 2011 disaster. REUTERS/Kyodo

Author

Anna Nagurney
John F. Smith Memorial Professor of Operations Management, University of Massachusetts Amherst

Disclosure statement

Anna Nagurney does not work for, consult, own shares in or receive funding from any company or organization that would benefit from this article, and has disclosed no relevant affiliations beyond the academic appointment above.

Partners

UMASS AMHERST

University of Massachusetts Amherst provides funding as a founding partner of The Conversation US.

Email

The number of disasters has doubled globally since the 1980s, with the

Chicago Tribune

SPORTS BREAKING HOY MOST POPULAR OPINION SUBURBS ENTERTAINMENT ADVERTISING

Response to natural disasters like Harvey could be helped with game theory

By Anna Nagurney
Associated Press

AUGUST 29, 2017 | BOSTON, MASSACHUSETTS

(The Conversation is an independent and nonprofit source of news, analysis and commentary from academic experts.)

Anna Nagurney, University of Massachusetts Amherst

(THE CONVERSATION) The devastation by Hurricane Harvey continues, with the National Weather Service calling the event unprecedented, thus making the response even more complicated.

Nearly half a million people are expected to seek federal aid in the aftermath of the Category 4 hurricane, which already has dumped more than 30 inches on the Houston

SALON VIDEO NEWS POLITICS ENTERTAINMENT LIFE

THURSDAY, AUG 31, 2017 10:38 AM EST

Time for some game theory: How responses to natural disasters like Harvey could be improved

The damage and losses from natural disasters are estimated to cost us $100 billion a year since 2000

ANNA NAGURNEY, THE CONVERSATION

Homeland Security News Wire

BIOMETRICS BORDER/IMMIG. BUSINESS CYBERSECURITY
PUBLIC SAFETY PUBLIC HEALTH REGIONAL SCI-TECH

Disaster response

How disaster relief efforts could be improved with game theory

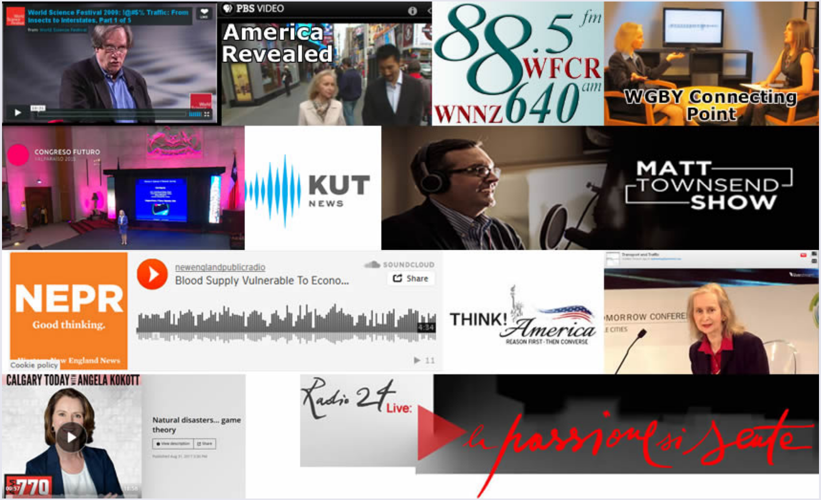
By Anna Nagurney

Published 13 March 2017

Share

The number of disasters has doubled globally since the 1980s, with the damage and losses estimated at an average

Coverage by the Media



On March 11, 2020 the WHO declared the pandemic. On March 12 my article on blood supply chains in *The Conversation* **appeared and, on March 24 my article in INFORMS** *Analytics Coronavirus Chronicles***.**

THE CONVERSATION
Academic rigor, journalistic flair

How coronavirus is upsetting the blood supply chain

March 12, 2020 8.06am EDT

Email
Twitter 28
Facebook 1.1k
LinkedIn
Print

The coronavirus, which causes the disease COVID-19, has created enormous anxiety, uncertainty, and disruption to our lives. Much has already been written about potential shortages of medicines and face masks, but little has been said about something only you and I can provide – lifesaving blood.

Our nation's blood supply is essential to our health care security. Blood transfusions are integral parts of major surgeries. Blood is used in the treatment of diseases, particularly sickle cell anemia and some cancers. Blood is needed for victims who have injuries caused by accidents or natural disasters. Every day, the U.S. needs 36,000 units of red blood cells, 7,000 units of platelets, and 10,000 units of plasma.

I am a professor and director of the Virtual Center for Supernetworks at the University of Massachusetts Amherst. Because of the escalating coronavirus health care crisis, I am deeply concerned the U.S. blood supply chain is under stress. The timing could hardly be worse; the COVID-19 outbreak coincides with our seasonal flus and colds.

Patients need blood in many states

Analytics
DRIVING BETTER BUSINESS DECISIONS
informs

March 24, 2020 in Coronavirus Chronicles

The COVID-19 Pandemic and the Stressed Blood Supply Chain

By Anna Nagurney

SHARE: PRINT ARTICLE: https://doi.org/10.1287/LYTX.2020.02.18

Blood is essential to our nation's healthcare security. It is a life-saving product that cannot be manufactured and comes solely from volunteer donors. No substitute for blood has yet been invented. Blood transfusions are integral parts of major surgeries. Blood is a must for saving victims of accidents and natural disasters. Blood is also used in the treatment of certain diseases, including certain cancers. In the United States, 36,000 units of red blood cells are needed daily as are 7,000 units of platelets and 10,000 units of plasma. A typical donation of one pint, which can be divided into red blood cells, plasma and platelets, can save up to three lives. Adults have 8-12 pints of blood.

Even in the best of times, the complex blood supply chain in the United States is under stress. Although 38% of the U.S. population is eligible to donate blood, less than 10% actually does so in a year. Furthermore, issues of seasonality come into play with flu and colds cutting donations; the same for weather-related events and holidays. To further complicate matters, blood is perishable; platelets last five days and red blood cells have a shelf life of 42 days.

The blood banking industry, entrusted with maintaining a sufficient supply of blood, is facing a battle of the century with the COVID-19 pandemic. The timing could not be worse with this year's heavy flu and cold season, and the blood banking industry having recently undergone a massive transformation due to both economics and changes in medical procedures [1]. For example, there is increased competition among blood service organizations for donors [2]. The American Red Cross has closed some testing facilities and even eliminated mobile collection units in parts of the country. There have also been mergers and acquisitions of blood service organizations [3]. On the other hand, hospitals are now requiring less blood for certain procedures as compared to a few years ago because of changes in medical practices. This has resulted in requests for lower prices for blood from blood banks, who still have to cover costs, and some of the new costs include higher testing costs due to diseases such as Zika. And now, because of the COVID-19 pandemic, a major source of blood donations – schools – is removed.

The critical blood supply chain is unique from others that we study in operations research (O.R.) because it requires

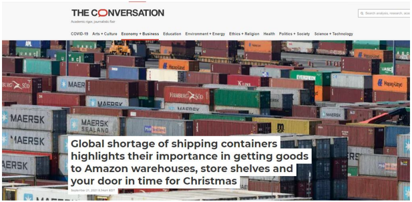
Writing OpEds in the Pandemic

On August 4, 2020, I published an article in *The Conversation*,

"The Raging Competition for Medical Supplies is not a Game, but Game Theory Can Help."

On September 18, 2020, I published another article in *The Conversation*,

"Keeping Coronavirus Vaccines at Subzero Temperatures During Distribution Will Be Hard, but Likely Key to Ending Pandemic."



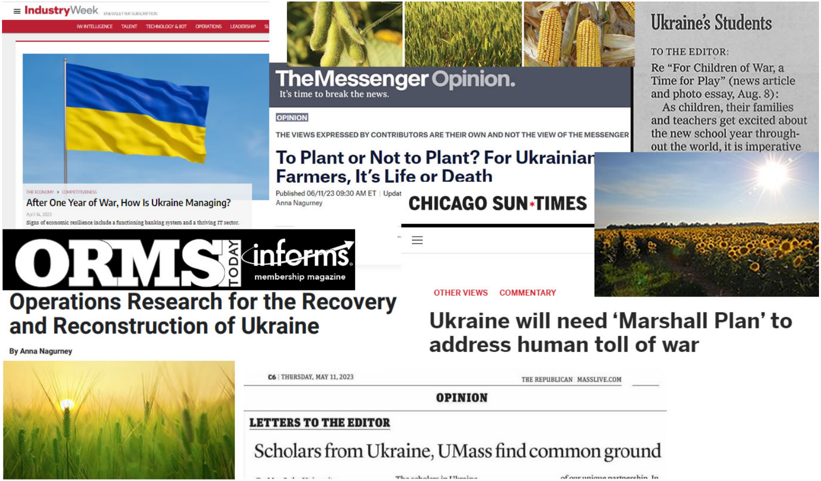
On April 5, 2021, I published the article,

"Today's Global Economy Runs on Standardized Containers, as the Ever Given Fiasco Illustrates," also in *The Conversation*.

On September 21, 2021, my article,

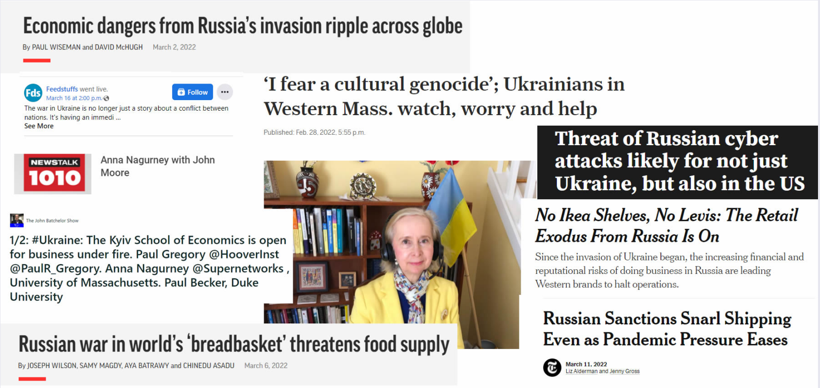
"Global Shortage of Shipping Containers Highlights Their Importance in Getting Goods to Amazon Warehouses, Store Shelves and Your Door in Time for Christmas," appeared in *The Conversation*. It has had over 330,000 reads.

Writings After the Full-Scale Invasion



Some of My Media Interviews in the Pandemic

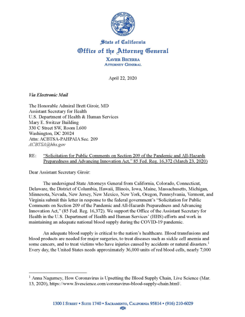
Some of the Media Interviews on the War on Ukraine



Impacting Policy

On April 22, 2020, a letter from California Attorney General Xavier Becerra to Admiral Brett Giroir, the Assistant Secretary of the US Department of Health & Human Services, and signed by US Attorney Generals of 21 other states, requested updates, because of the pandemic blood shortages, to blood donation policies that discriminate.

My March 2020 article in *The Conversation*, **which was reprinted in LiveScience, was the first reference and was cited on the first page.**



State of California
Office of the Attorney General
Xavier Becerra
Attorney General

April 22, 2020

Via Electronic Mail

The Honorable Admiral Brett Giroir, MD
Assistant Secretary for Health
U.S. Department of Health & Human Services
Mary E. Switzer Building
330 C Street SW, Room L600
Washington, DC 20024
Attn: ACBTSA-PAHPAIA Sec. 209
ACBTSA@hhs.gov

RE: "Solicitation for Public Comments on Section 209 of the Pandemic and All-Hazards Preparedness and Advancing Innovation Act," 85 Fed. Reg. 16,372 (March 23, 2020)

Dear Assistant Secretary Giroir:

The undersigned State Attorneys General from California, Colorado, Connecticut, Delaware, the District of Columbia, Hawaii, Illinois, Iowa, Maine, Massachusetts, Michigan, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Vermont, and Virginia submit this letter in response to the federal government's "Solicitation for Public Comments on Section 209 of the Pandemic and All-Hazards Preparedness and Advancing Innovation Act," (85 Fed. Reg. 16,372). We support the Office of the Assistant Secretary for Health in the U.S. Department of Health and Human Services' (HHS) efforts and work in maintaining an adequate national blood supply during the COVID-19 pandemic.

An adequate blood supply is critical to the nation's healthcare. Blood transfusions and blood products are needed for major surgeries, to treat diseases such as sickle cell anemia and some cancers, and to treat victims who have injuries caused by accidents or natural disasters.[1] Every day, the United States needs approximately 36,000 units of red blood cells, nearly 7,000

[1] Anna Nagurney, How Coronavirus is Upsetting the Blood Supply Chain, Live Science (Mar. 13, 2020), https://www.livescience.com/coronavirus-blood-supply-chain.html/.

1300 I Street • Suite 1740 • Sacramento, California 95814 • (916) 210-6029

Hon. Brett Giroir
April 22, 2020
Page 7

WILLIAM TONG
Connecticut Attorney General

KATHLEEN JENNINGS
Delaware Attorney General

KARL A. RACINE
District of Columbia Attorney General

CLARE E. CONNORS
Hawaii Attorney General

KWAME RAOUL
Illinois Attorney General

TOM MILLER
Iowa Attorney General

AARON M. FREY
Maine Attorney General

MAURA HEALEY
Massachusetts Attorney General

DANA NESSEL
Michigan Attorney General

KEITH ELLISON
Minnesota Attorney General

AARON D. FORD
Nevada Attorney General

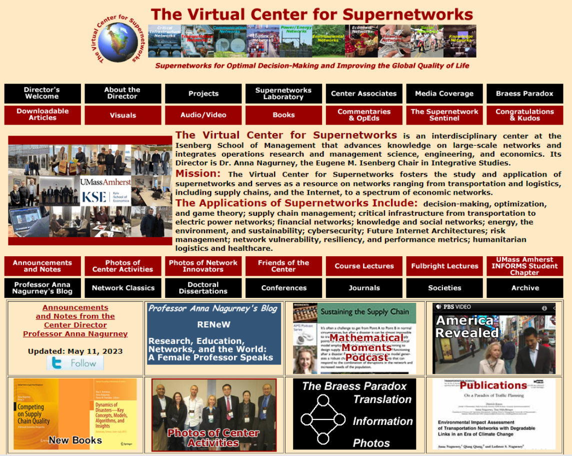
GURBIR S. GREWAL
New Jersey Attorney General

HECTOR BALDERAS
New Mexico Attorney General

LETITIA JAMES
New York Attorney General

Xavier Becerra, then CA Attorney General, is now Secretary of Health and Human Services in the United States!

Thank You Very Much!



More information on our work can be found on the Supernetwork Center site:
https://supernet.isenberg.umass.edu/