Agricultural Supply Chain Networks Under Uncertainty

Professor Anna Nagurney

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

CORS Micro-Event
April 11, 2025

Acknowledgments

Many thanks to Professor Anjali Awasthi, the President of CORS, for the invitation to speak with you today!

CORS·SCRO

Canadian Operational Research Society

Société canadienne de recherche opérationnelle

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

Outline of This Presentation

- Background and Motivation
- Our Approach to Supply Chains
- Food Supply Chains and Disruptions
- International Agricultural Trade and Disasters
- The Multicommodity International Trade Model
- International Trade Network Performance Indicator
- Unified International Trade Network Performance Measure
- Robustness Measurement
- Importance Indicator of an International Trade Network Component
- 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

For the Love of **Operations Research (OR) and Networks**

From my first course at Brown University on the subject to my first projects in industry - working on naval submarines in Newport, Rhode Island, I was drawn to the power of networks, especially when combined with computing.

Off to Grad School for a PhD

While working in high tech defense consulting I realized that I did not like having a boss. I commuted, ran marathons, and worked full time while taking courses for my Master's at Brown.

Dr. Stella Dafermos was the only female professor at the time in either Engineering or Applied Mathematics at Brown University. I became her first PhD student.

EQUILIBRIUM MODELING, ANALYSIS AND COMPUTATION: THE CONTRIBUTIONS OF STELLA DAFERMOS

ANNA NAGURNEY

University of Massachusetts, Amherst, Massachusetts

(Received June 1990; accepted August 1990)

This memorial tribute to the late Stella Dafermos summarizes her contributions to equilibrium modeling, analysis, and computation, and provides a list of her published papers.

On April 5, 1990, with the death at 49 of Stella Dafermos, Professor of Applied Mathematics and Engineering at Brown University, Providence, Rhode Island, the operations research community lost one of its early woman doctorates. Throughout her quarter-century career she dedicated herself to developing rigorous mathematical formalisms for modeling, analyzing and making computations related to competitive equilibrium systems that spanned applications from congested urban transportation networks to multicommodity trade. Beginning with her 1968 doctoral dissertation, "Traffic Assignment and Resource Allocation in Transportation Networks," directed by F. T. Sparrow at Johns Hopkins University, which focused on the study of system-optimized and user-optimized transportation networks, she initiated a theme of advancement of methodologies by which the behavior of complex systems could be captured and studied.

EQUILIBRIUM MODELING

In her first paper, based on her thesis and published in 1969, she proposed convergent equilibration algorithms that simulated the adjustment behavior of travelers on a congested network operating in their own self-interest in choosing their routes. The governing equilibrium conditions, due to Wardrop, reflected that only the minimum cost routes connecting each origin/destination pair would be used. These algorithms took advantage of the problem structure and were later extended in papers published in 1971 and 1972 to network models that allowed for interaction among users of the system via the link cost functions. In her 1969 paper she also focused on stability issues, which began the theme of qualitative analysis of equilibrium patterns that was also to pervade her scholarly work.

These network equilibrium models, as well as the integrated models that allowed for both location and route choice, developed in her paper of 1976, were formulated as optimization problems, with the observation that the equilibrium conditions governing these problems were actually the Kuhn-Tucker conditions of an appropriately constructed optimization problem. Interestingly, parallel to these developments in nonlinear networks, the economics community was reformulating spatial price equilibrium problems, in which commodities are produced, consumed and traded, subject to transportation or transaction costs, as optimization problems. However, the assumption required for such a transformation—that of *symmetry*, in which cross-effects of various interactions had to be identical—precluded the realistic modeling of multiple modes of transportation and different classes of users of a given system, as well as multiple commodities. Moreover, the objective function thus constructed, although convenient and essential given the state-of-the-art at the time, was artificial. Furthermore, equilibrium problems, by their very nature, involve more than a single agent and objective function, with interactions among the agents, and, hence, the objective functions being the rule rather than the exception. To overcome such shortcomings, a methodological advance was needed.

In 1980 Stella made a fundamental discovery by observing that the equilibrium conditions of the traffic assignment problem actually had the structure of a variational inequality problem. Although the theory of variational inequalities had been introduced over a decade earlier for the study of partial differential equations, the emphasis there was on infinite-dimensional problems arising in mechanics, and its use as a powerful tool for equilibrium analysis in operations research was left unrealized. Stella's identification of network equilibrium conditions with a variational inequality problem opened up new horizons for mathematical modeling, analysis and the efficient computation of more general equilibrium systems than had heretofore been possible. With this

Subject classifications: Economics: solution of equilibrium problems. Networks/graphs: equilibrium modeling and computation. Transportation: formulation and solution of multimodal problems.

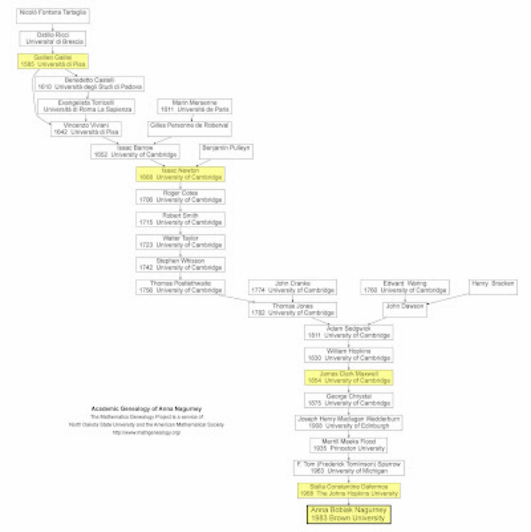
Operations Research
Vol. 39, No. 1, January-February 1991

9

0030-364X/91/3901-0008 $01.25
© 1991 Operations Research Society of America

Stella was only the second female in the US to have received a PhD in OR and that was from Johns Hopkins University.

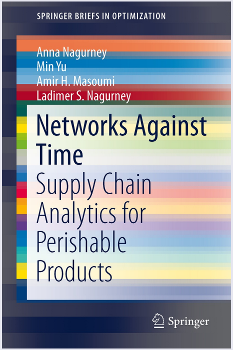
On the Shoulders of Giants - My Academic Genealogy - **Maxwell, Newton, and Galileo**



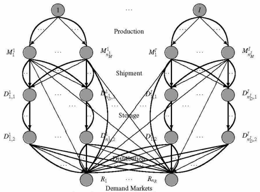
Our Approach to Supply Chains

A Multidisciplinary Approach

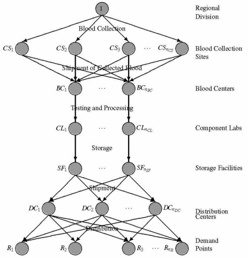
In our research on perishable and time-sensitive product supply chains, we utilize results from physics, chemistry, biology, and medicine in order to capture the perishability of various products over time from healthcare products such as blood, medical nucleotides, and pharmaceuticals to food.



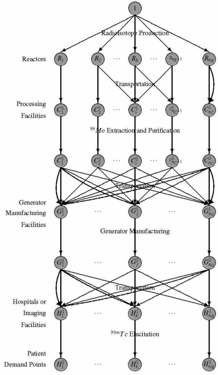
Some of the Supply Chain Network Topologies



The Pharmaceutical Supply Chain Network Topology

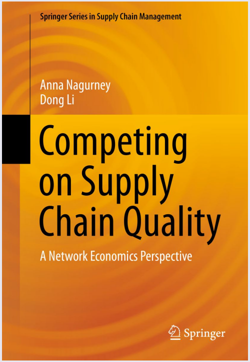


Supply Chain Network Topology for a Regionalized Blood Bank



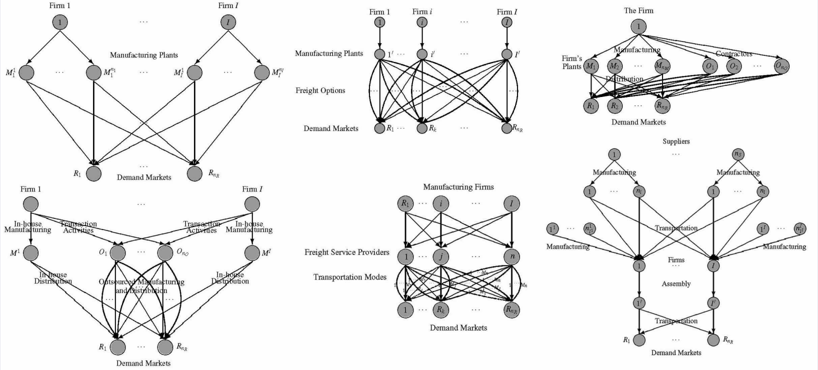
The Medical Nuclear Supply Chain Network Topology

Research on Quality is Related to That on Perishability



Examples of product quality failures have included: • adulterated infant formula • inferior pharmaceuticals • defective airbags • defective ignition switches • bacteria-laden food • exploding smartphones • expired masks in the national stockpile, etc.

In the book, we present supply chain network models and tools to investigate, amongst other topics, information asymmetry, impacts of outsourcing on quality, minimum quality standards, applications to industries such as pharma, freight services and quality, and **the identification of which suppliers matter the most to both individual firms' supply chains and to that of the supply chain network economy**.



The COVID-19 Pandemic and Other Crises and Disasters

The COVID-19 pandemic dramatically and vividly demonstrated the importance of supply chains and their resilience as shortages from PPEs to paper and lumber products, cleaning supplies, high tech products, and various foods were experienced.

Major challenges and opportunities for research continue due to climate change, different kinds of threats, wars, violence and increasing strife and unrest.

The tools of Operations Research are very powerful and timely to assist in the necessary math modeling, analyses, efficient algorithms, and prescriptive analytics, coupled with policy evaluation.

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, wars, and other disasters (both sudden-onset and slow-onset ones).

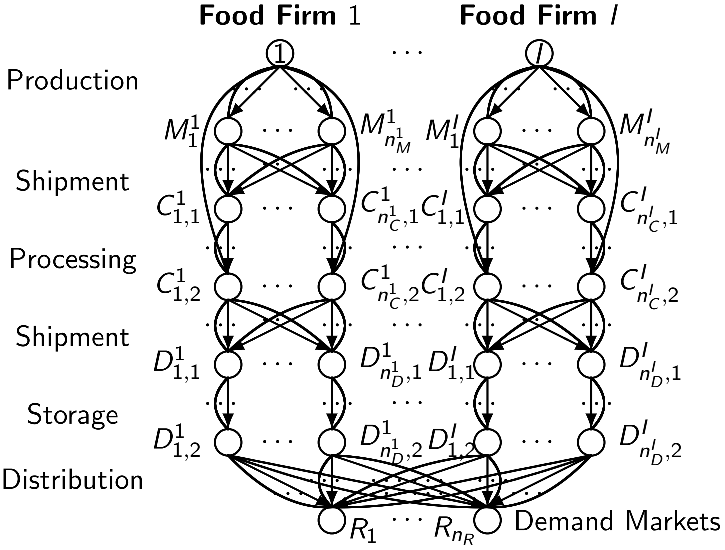
Fresh Produce Food Supply Chains

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.**

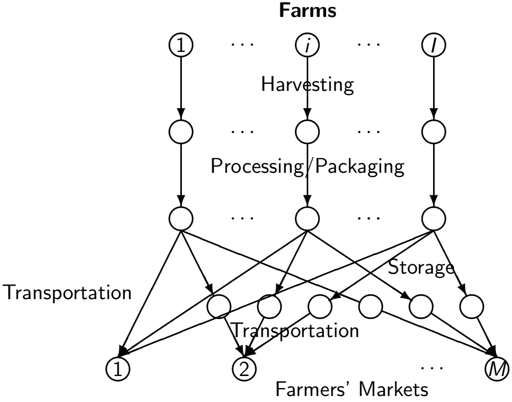
Fresh Produce Food Supply Chains



The Fresh Produce Supply Chain Network Topology

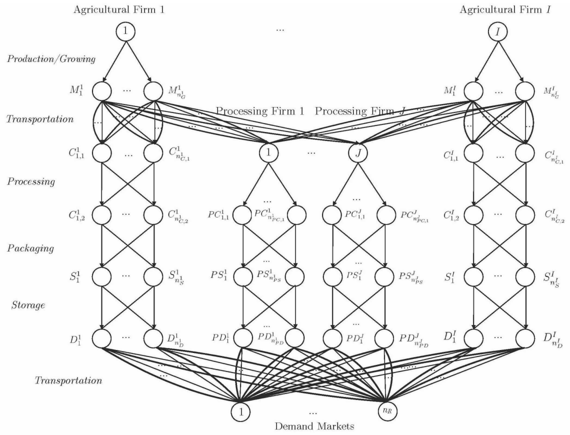
Farmers' Markets and Fresh Produce Supply Chains

- 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

The Christian Science Monitor

Lacking seasonal workers, Italy elevates its long-shunned migrants

DENVER 7 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

It's All About People

A major research theme of ours in the COVID-19 pandemic (which continues) was the inclusion of labor in supply chains, using optimization and game theory.

ORMS TODAY informs. membership magazine

NEWS FEATURES PODCASTS

January 29, 2021 in Supply Chain Networks

In the End, It's All About People

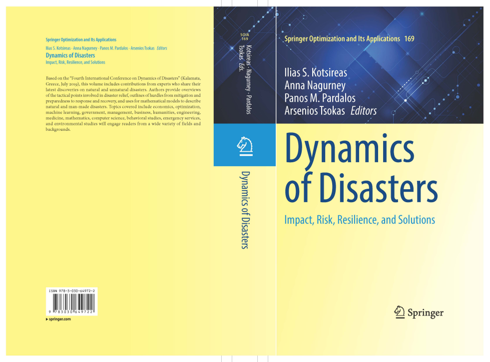
COVID-19 vaccine production reveals dependency on supply chains, labor workforce in the U.S.

By Anna Nagurney

SHARE: PRINT ARTICLE: https://doi.org/10.1287/orms.2021.01.17

The COVID-19 pandemic has dramatically revealed how dependent we are on supply chains and the availability of labor. Without the human element, meatpacking plants cannot function; fresh produce cannot be picked; grocery stores cannot be shelved; PPEs cannot be produced and distributed; and products cannot be delivered to our homes through e-commerce. Also, COVID-19 vaccine production may lack the human resources to ensure product quality

"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.**



Perishable Food Supply Chain Network Model with Labor

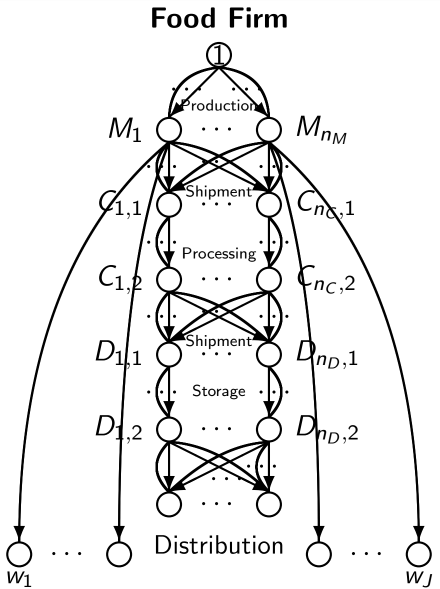


Figure: The Perishable Food Supply Chain Network Topology

- **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**.

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
0377-2217/© 2021 Elsevier B.V. All rights reserved.

Game Theory Supply Chain Network Model with Labor

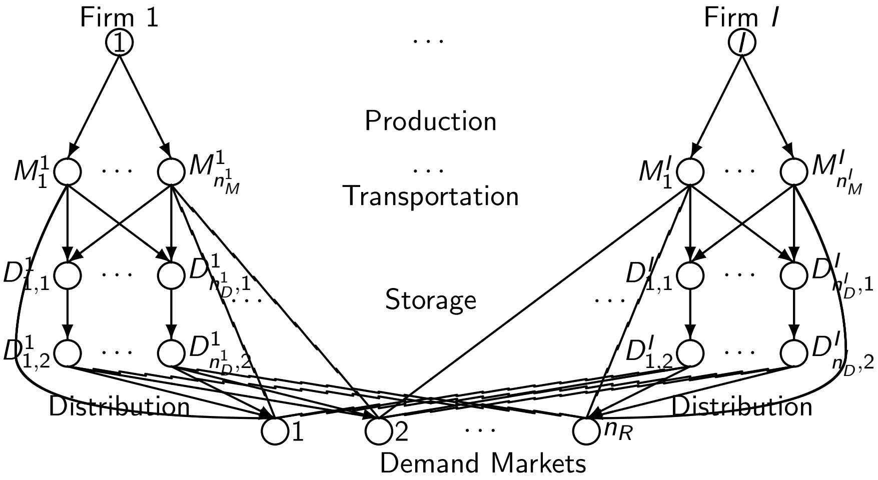


Figure: The Supply Chain Network Topology of the Game Theory Model with Labor

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!

Resilience of Supply Chains to Labor Disruptions

•**Question 1:** What is the impact on efficiency and on resilience of allowing workers to perform different tasks in a supply chain network, with the constraint represented by a single bound on labor, as opposed to bounds on labor on each supply chain link?

• **Question 2:** Does resilience with respect to labor availability yield similar results to resilience with respect to labor productivity?

• **Question 3:** What can be the effect of a modification in the supply chain network topology, for example, as in the case of the introduction of electronic commerce, on network efficiency and resilience?

The paper proposes two resilience measures with respect to (1) labor availability disruptions and (2) labor productivity disruptions.

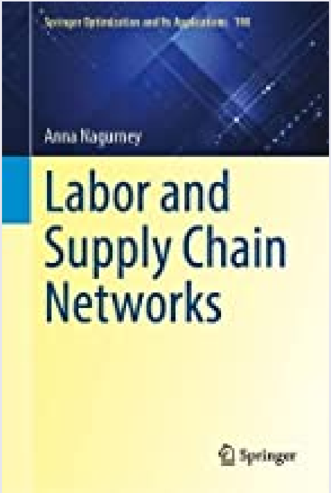
Solving five distinct supply chain network examples, we find:

(1). A free movement of labor across the supply chain network results in a higher efficiency of the supply chain as well as a higher resilience.

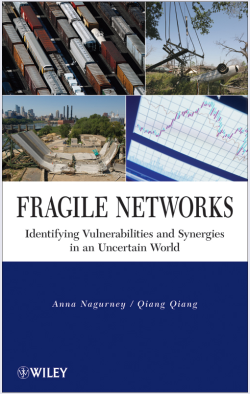
(2). A reduction in labor productivity can impact the supply chain network efficiency and the corresponding resilience.

(3). The presence of electronic commerce escalates the efficiency of the supply chain network but diminishes resilience.

New Book



One of my books, written with a UMass Amherst Isenberg School PhD alum, was "hacked" and digital copies of it posted on websites around the globe.



In a sense, this may be viewed as a compliment since clearly someone had determined that it has some sort of *value*.

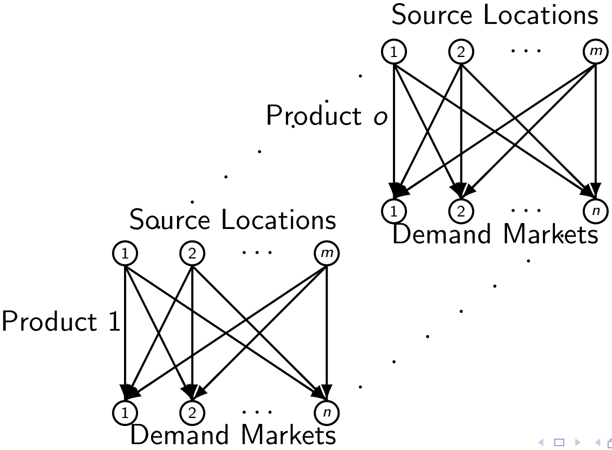
Cybercrime and Cybersecurity

The publisher John Wiley & Sons was notified and lawyers got involved but how do you contact and then influence those responsible for postings on rather anonymous websites?

Clearly, hackers go where there is money.

Perishability and Cybercrime in Financial Products

The paper, "A Multiproduct Network Economic Model of Cybercrime in Financial Services," A. Nagurney, *Service Science* **7(1) (2015) pp 70-81 provides insights into the perishability of value of credit cards.**



International Trade and Challenges

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

World's Biggest Importers

Largest Importers In The World

In 2022, global imports climbed to $25.6 trillion in value, or about the size of the U.S. GDP. As an engine of growth, global trade broadens consumer choices and can lower the cost of goods. For businesses, it can improve the quality of inputs and strengthen competitiveness.

***(in Billion USD)**

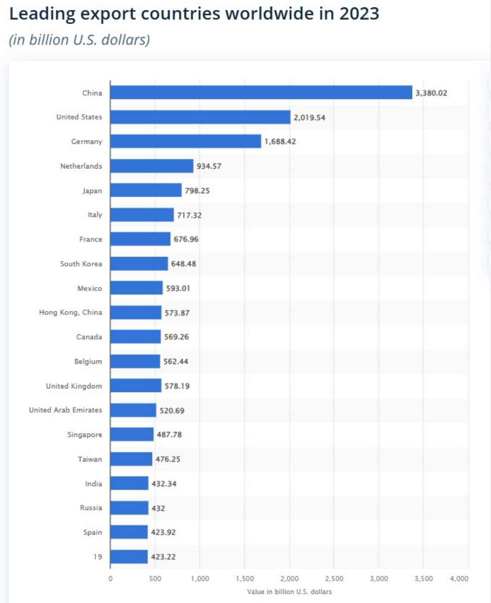
United States	$3,376B
China	$2,716B
Germany	$1,571B
Netherlands	$899B
Japan	$897B
United Kingdom	$824B
France	$818B
South Korea	$731B
India	$723B
Italy	$689B
Hong Kong SAR	$668B
Mexico	$626B
Belgium	$621B
Canada	$582B
Spain	$493B
Singapore	$476B
Taiwan	$436B
UAE	$425B
Poland	$381B
Türkiye	$364B
VietNam	$359B
Switzerland	$356B
Australia	$309B
Thailand	$303B
Malaysia	$294B
Brazil	$290B
Russia	$242B
Indonesia	$237B
Czech Republic	$236B
Austria	$232B
Sweden	$202B
Saudi Arabia	$188B
Hungary	$163B
Ireland	$146B
Philippines	$144B
South Africa	$136B
Romania	$132B
Denmark	$127B
Portugal	$115B
Slovakia	$113B

Source: World Trade Organization, USAFacts

www.rankingroyals.com

RankingRoyals

World's Biggest Exporters



Global Trade Policies

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

Tariffs Are Regularly in the News!

The imposition of tariffs by certain countries is leading to retaliation by other countries with ramifications across multiple supply chains, and a trade war.

With Higher Tariffs, China Retaliates Against the U.S.

The Yangshan Deep Water Port in Shanghai, China. The Chinese government said on Monday that it would raise tariffs on goods from the United States as of June 1, giving negotiators from the two countries time to strike a deal. Aly Song/Reuters

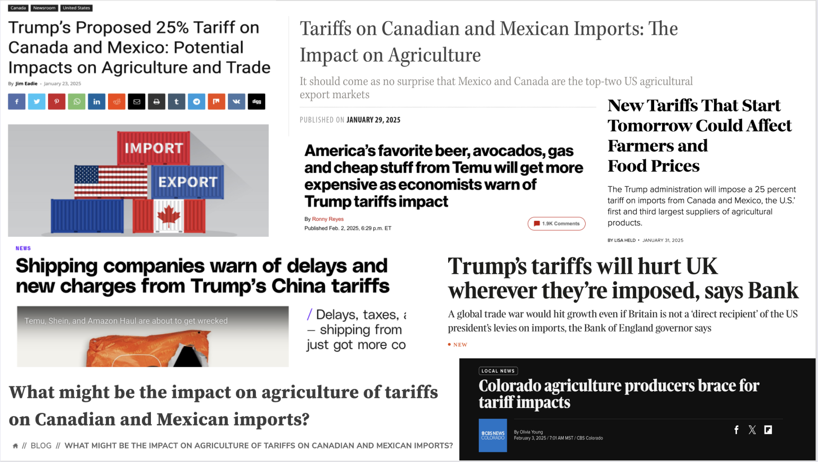
Trump's Tariffs Would Deal a Big Blow to the Auto Industry

Automakers and parts suppliers would struggle if President-elect Donald J. Trump followed through on his threat to impose 25 percent tariffs on imports from Canada and Mexico.

Nissan and other automakers are cutting thousands of jobs as they struggle to cope with sagging demand and a growing preference for hybrid and electric cars. Liberto Urena/Reuters

President-elect Donald J. Trump's threat to impose 25 percent tariffs on goods from Mexico and Canada sent shivers on Tuesday through the auto industry, which depends heavily on both countries for parts and manufacturing.

Tariffs Are Regularly in the News!



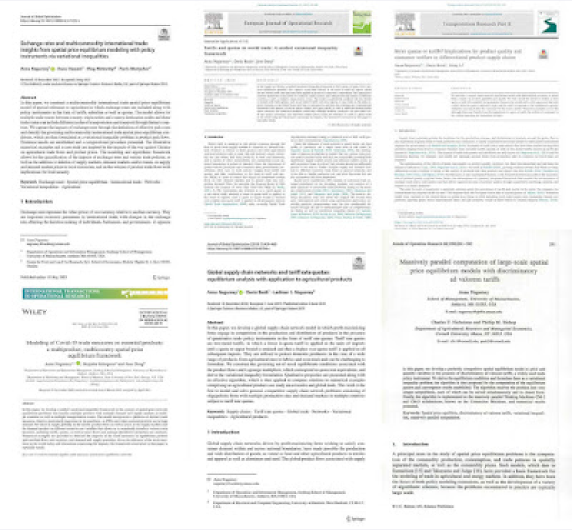
We have been developing computable operational mathematical models that enable the assessment of the impacts of trade policy instruments such as tariff rate quotas on consumer prices, trade flows, as well as on the profits of producers/firms.

This is very challenging research!

Motivation

- 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.**

Some of Our Papers on Tariffs and Other Policies


European Journal of Operational Research

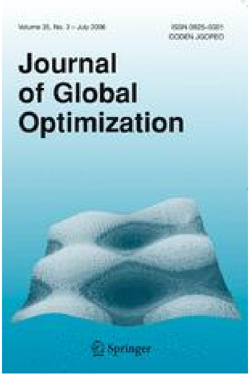
Transportation Research Part E

Global supply chain networks and tariff rate quotas: equilibrium analysis with application to agricultural products

Massively parallel computation of large-scale spatial price equilibrium models with discriminatory ad valorem tariffs

An Example of Our Trade Policy Research

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.**



Another Example of Our Trade Policy Research

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.**

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.

Disasters and 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 on February 24, 2022, around 47 million people are estimated to have been added to the more than 276 million who were already facing food insecurity.**
- **Critical links such as the Panama Canal and the Red Sea and Suez Canal have been disrupted because of a drought affecting the former and Houthi attacks the latter.**

Acknowledgment

I acknowledge the partnership between the University of Massachusetts Amherst and the Kyiv School of Economics, which facilitated our research on international agricultural trade.

UMass Amherst KSE | Kyiv School of Economics

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

Anna Nagurney, Dana Hassani, Oleg Nivievskyi, and Pavlo Martyshev

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 chapter, 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.

A. Nagurney (✉) · D. Hassani
Department of Operations and Information Management, Isenberg School of Management, University of Massachusetts, Amherst, MA, USA
e-mail: nagurney@isenberg.umass.edu

O. Nivievskyi · P. Martyshev
Center for Food and Land Use Research, Kyiv School of Economics, Kyiv, Ukraine

 151
I. S. Kotsireas et al. (eds.), *Dynamics of Disasters*, Springer Optimization and Its Applications 217, https://doi.org/10.1007/978-3-031-74006-0_7

informs.
https://pubsonline.informs.org/journal/trsc

TRANSPORTATION SCIENCE
Vol. 59, No. 1, January–February 2025, pp. 143–164
ISSN 0041-1655 (print), ISSN 1526-5447 (online)

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

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

[a] Department of Operations and Information Management, Isenberg School of Management, University of Massachusetts, Amherst, Massachusetts 01003; [b] Center for Food and Land Use Research, Kyiv School of Economics, 02000 Kyiv, Ukraine
*Corresponding author
Contact: dhassani@umass.edu, https://orcid.org/0000-0002-5648-6304 (DH); nagurney@isenberg.umass.edu, https://orcid.org/0000-0002-1645-5363 (AN); onivievskyi@kse.org.ua, https://orcid.org/0000-0002-8902-9453 (ON); pmartyshev@kse.org.ua (PM)

Received: August 26, 2023
Revised: February 25, 2024; July 11, 2024
Accepted: July 18, 2024
Published Online in Articles in Advance: August 28, 2024

https://doi.org/10.1287/trsc.2023.0294

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

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. It has severely impacted the economy of Ukraine with repercussions globally. Food insecurity is rising because the associated disruptions and destruction because of the war have been especially severe in the agricultural sector. ... and the impeded transport of Ukrainian grain. The Food and Agriculture Organization (2022) of the United Nations estimates that between 20% and 30% of the arable land in Ukraine will remain idle because of mining and other damages because of the invasion, resulting in around a 40% decrease in the production of grain in Ukraine as compared with prewar production levels. In terms of the transportation of grain from Ukraine to the countries that heavily rely on these food supplies to meet the nutritional demands of their populations, especially Middle East and North Africa (MENA) countries such as Egypt and Lebanon, the blockade of the Ukrainian Black Sea ports, which used to handle around 90% of the grain ... nificantly lower than prewar levels because of the safety risks for the ships and slow inspections forced on the shipments (Ukrainska Pravda 2023).

Furthermore, as the war continues and with the news, as of July 17, 2023, that Russia has suspended the

European Journal of Operational Research 314 (2024) 1127–1142

Contents lists available at ScienceDirect
ELSEVIER
European Journal of Operational Research
journal homepage: www.elsevier.com/locate/ejor

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]

[a] Department of Operations and Information Management, Isenberg School of Management, University of Massachusetts, Amherst, MA 01003, United States of America
[b] Center for Food and Land Use Research, Kyiv School of Economics, Mykoly Shpaka St. 3, Kyiv, 02000, Ukraine

ARTICLE INFO

Keywords:
Agriculture
Supply chains
Network equilibrium
International trade
Food security

ABSTRACT

The number of people affected by disasters, including man-made ones, is on the rise globally, with rising food insecurity being one of the most critical impacts. Disasters, both sudden-onset and slow-onset ones, can cause disruptions to the production and transportation of agricultural commodities. Having the tools that can quantitatively assess the changes in agricultural commodity shipment volumes and their prices under disruptions caused by disaster scenarios is of major importance. In this paper, we utilize the theory of variational inequalities as the methodology to construct a multicommodity international agricultural trade network equilibrium model, which contains novel features of capacities on the production and transportation of multiple agricultural commodities to capture competition. The model includes exchange rates and accounts for multiple routes and possibly distinct transportation modes and combinations. Theoretical results are given and an algorithm is proposed. A series of numerical examples, both illustrative and algorithmically solved ones, inspired by Russia's war on Ukraine, highlight the effects of reduced production and transportation capacities on food security in the Middle Eastern and North African (MENA) countries of Lebanon and Egypt. We also include sensitivity analysis results for exchange rates. The solutions reveal insights into the importance of the production and transportation capacities regarding food security, along with having multiple transportation routes that are cost-efficient as well as the importance of the magnitude of exchange rates.

1. Introduction

Our planet and people are being faced with immense challenges brought about by disasters ranging from those caused by natural phenomena (earthquakes, tornadoes, volcanic eruptions, tsunamis, hurricanes, floods, droughts, etc.) and those wrought by unnatural phenomena, caused by humans (wars, explosions, terrorist attacks, chemical spills, etc.). Some disasters, such as wildfires, may be caused by lightning (nature) or be man-made due to intentional, accidental, or because ...

... affordability and accessibility of agri-food products around the globe. With the added disruptions of what has become a de facto war in Europe, according to Belgrave (2022), around 47 million people are estimated to have been added to the more than 276 million who were already facing food insecurity, corresponding to an increase of about 17% in the food-insecure population, mainly in the vulnerable communities of Sub-Saharan Africa and the Middle East. The Food and Agriculture Organization (FAO) of the United Nations (2022) reports ...

https://doi.org/10.1007/s10898-023-01292-x

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

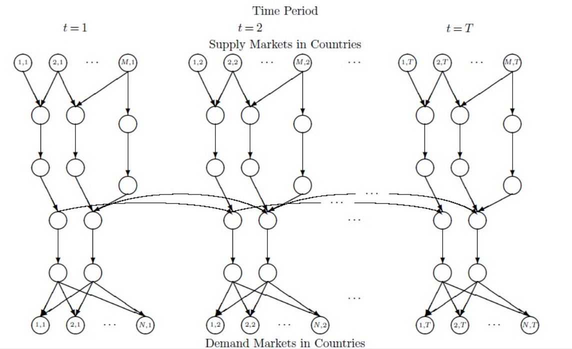
Exchange rates represent the value (price) of one currency relative to another currency. They are important economic parameters in international trade, with changes in the exchange rate affecting the decision-making of individuals, businesses, and governments. A separate

✉ Anna Nagurney
nagurney@isenberg.umass.edu

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

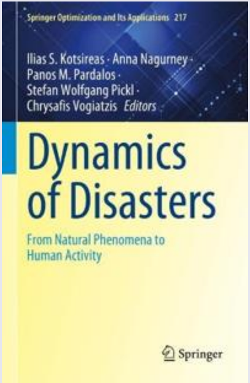
[2] Center for Food and Land Use Research, Kyiv School of Economics, Mykoly Shpaka St. 3, Kyiv 02000, Ukraine

A Multiperiod International Agricultural Trade Network Topology



D. Hassani, A. Nagurney, O. Nivievskyi, and P. Martyshev, "A Multiperiod, Multicommodity, Capacitated International Agricultural Trade Network Equilibrium Model with Applications to Ukraine in Wartime," *Transportation Science* **59(1) (2025), pp 143-164.**

New Edited Volume Published in December 2024



In the edited volume is the paper, "Quantification of International Trade Network Performance Under Disruptions to Supply, Transportation, and Demand Capacity, and Exchange Rates in Disasters," by A. Nagurney, D. Hassani, O. Nivievskyi, and P. Martyshev, pp 151-179.

The Multicommodity International Trade Model

The Multicommodity International Trade Model

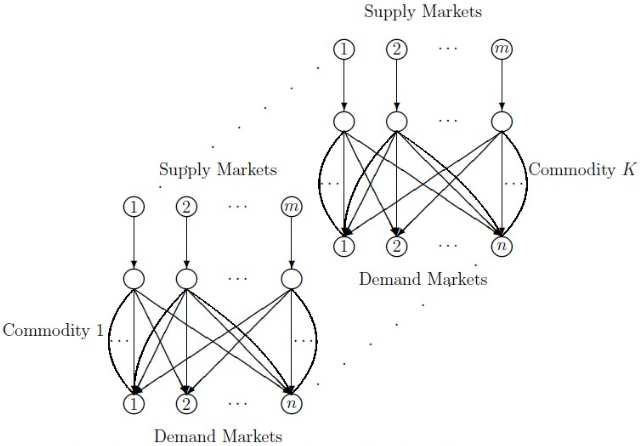


Figure 1: The Multicommodity International Trade Network

Parameters

Notation	Parameter Definition
$u_i^{s^k \xi_l}$	upper bound on supply of commodity k; $k = 1, \ldots, K$ at supply market i; $i = 1, \ldots, m$ under disaster scenario ξ_l; $l = 1, \ldots, \omega$.
$u_{ijr}^{Q^k \xi_l}$	upper bound on transport of commodity k; $k = 1, \ldots, K$ from supply market i; $i = 1, \ldots, m$ to demand market j; $j = 1, \ldots, n$ on route r; $r = 1, \ldots, P$ under disaster scenario ξ_l; $l = 1, \ldots, \omega$.
$u_j^{d^k \xi_l}$	upper bound on the demand of commodity k; $k = 1, \ldots, K$ at demand market j; $j = 1, \ldots, n$, under disaster scenario ξ_l; $l = 1, \ldots, \omega$. We group all the upper bounds for all the disaster scenarios into the vector u.
$e_{ij}^{\xi_l}$	exchange rate from supply market i; $i = 1, \ldots, m$ to demand market j; $j = 1, \ldots, n$ and disaster scenario ξ_l; $l = 1, \ldots, \omega$. We group the exchange rates for disaster scenario ξ_l; $l = 1, \ldots, \omega$ into the vector $e^{\xi_l} \in R_+^{mn}$ and then group all the exchange rates for all the disaster scenarios into the vector $e \in R_+^{mn\omega}$.

Variables

Notation	Variable Definition
$s_i^{k\xi_l}$	the supply of the commodity k; $k = 1,\ldots,K$, at supply market i; $i = 1,\ldots,m$ under disaster scenario ξ_l; $l = 1,\ldots,\omega$. We group all the supplies at disaster scenario ξ_l; $l = 1,\ldots,\omega$ into the vector $s^{\xi_l} \in R_+^{Km}$, and then group all the supplies for all the disaster scenarios into the vector $s \in R_+^{Km\omega}$.
$d_j^{k\xi_l}$	the demand for the commodity k; $k = 1,\ldots,K$ at demand market j; $j = 1,\ldots,n$ under disaster scenario ξ_l; $l = 1,\ldots,\omega$. We group all the demands at disaster scenario ξ_l; $l = 1,\ldots,\omega$ into the vector $d^{\xi_l} \in R_+^{Kn}$, and then group all the demands for all the disaster scenarios into the vector $d \in R_+^{Kn\omega}$.
$Q_{ijr}^{k\xi_l}$	the shipment of the commodity k; $k = 1,\ldots,K$, from supply market i; $i = 1,\ldots,m$, to demand market j; $j = 1,\ldots,n$, on route r; $r = 1,\ldots,P$ under disaster scenario ξ_l; $l = 1,\ldots,\omega$. We group all the commodity shipments at disaster scenario ξ_l; $l = 1,\ldots,\omega$ into the vector $Q^{\xi_l} \in R_+^{KmnP}$, and then group all the commodity shipments into the vector $Q \in R_+^{KmnP\omega}$.

Functions

Notation	Function Definition
$\pi_i^k(s^{\xi_l})$	the supply price function for commodity k; $k = 1, \dots, K$, at supply market i; $i = 1, \dots, m$ under disaster scenario ξ_l; $l = 1, \dots, \omega$.
$\rho_j^k(d^{\xi_l})$	the demand price function for commodity k; $k = 1, \dots, K$ at demand market j; $j = 1, \dots, n$ under disaster scenario ξ_l; $l = 1, \dots, \omega$.
$c_{ijr}^k(Q^{\xi_l})$	the unit transportation cost associated with shipping the commodity k; $k = 1, \dots, K$, from supply market i; $i = 1, \dots, m$, to demand market j; $j = 1, \dots, n$ via route r; $r = 1, \dots, P$ under disaster scenario ξ_l; $l = 1, \dots, \omega$.

Equilibrium Conditions

Definition 1: The Multicommodity International Trade Network Equilibrium Conditions Under Capacity Disruptions in Disasters

A shipment and Lagrange pattern $(Q^{\xi_l *}, \lambda^{s\xi_l *}, \lambda^{Q\xi_l *}, \lambda^{d\xi_l *}) \in \mathcal{K}^{\xi_l}$, *where*

$$\mathcal{K}^{\xi_l} \equiv \{(Q^{\xi_l}, \lambda^{s\xi_l}, \lambda^{Q\xi_l}, \lambda^{d\xi_l}) | (Q^{\xi_l}, \lambda^{s\xi_l}, \lambda^{Q\xi_l}, \lambda^{d\xi_l}) \in R_+^{KmnP+Km+KmnP+Kn}\}$$

is a multicommodity international trade network equilibrium under disaster scenario ξ_l; $l = 1, \ldots, \omega$, *if the following conditions hold: for all commodities* k; $k = 1, \ldots, K$; *for all supply and demand market pairs:* (i, j); $i = 1, \ldots, m$; $j = 1, \ldots, n$, *and for all routes* r; $r = 1, \ldots, P$:

$$(\tilde{\pi}_i^k(Q^{\xi_l *}) + c_{ijr}^k(Q^{\xi_l *}))e_{ij}^{\xi_l} + \lambda_i^{s^k \xi_l *} + \lambda_{ijr}^{Q^k \xi_l *} + \lambda_j^{d^k \xi_l *} \begin{cases} = \tilde{\rho}_j^k(Q^{\xi_l *}), \ \text{if } Q_{ijr}^{k\xi_l *} > 0, \\ \geq \tilde{\rho}_j^k(Q^{\xi_l *}), \ \text{if } Q_{ijr}^{k\xi_l *} = 0; \end{cases} \quad (1)$$

Equilibrium Conditions

For all commodities k; $k = 1, \ldots, K$, and for all supply markets i; $i = 1, \ldots, m$:

$$u_i^{s^k \xi_l} \begin{cases} = \sum_{j=1}^{n} \sum_{r=1}^{P} Q_{ijr}^{k\xi_l *}, & \text{if } \lambda_i^{s^k \xi_l *} > 0, \\ \geq \sum_{j=1}^{n} \sum_{r=1}^{P} Q_{ijr}^{k\xi_l *}, & \text{if } \lambda_i^{s^k \xi_l *} = 0; \end{cases} \tag{2}$$

for all commodities k; $k = 1, \ldots, K$, and for all supply and demand markets (i, j); $i = 1, \ldots, m$; $j = 1, \ldots, n$, and for all routes r; $r = 1, \ldots, P$:

$$u_{ijr}^{Q^k \xi_l} \begin{cases} = Q_{ijr}^{k\xi_l *}, & \text{if } \lambda_{ijr}^{Q^k \xi_l *} > 0, \\ \geq Q_{ijr}^{k\xi_l *}, & \text{if } \lambda_{ijr}^{Q^k \xi_l *} = 0; \end{cases} \tag{3}$$

and for all commodities k; $k = 1, \ldots, K$, and for all demand markets j; $j = 1, \ldots, n$, and for all routes r; $r = 1, \ldots, P$:

$$u_j^{d^k \xi_l} \begin{cases} = \sum_{i=1}^{m} \sum_{r=1}^{P} Q_{ijr}^{k\xi_l *}, & \text{if } \lambda_j^{d^k \xi_l *} > 0, \\ \geq \sum_{i=1}^{m} \sum_{r=1}^{P} Q_{ijr}^{k\xi_l *}, & \text{if } \lambda_j^{d^k \xi_l *} = 0. \end{cases} \tag{4}$$

Variational Inequality Formulation

Theorem 1

A multicommodity shipment and Lagrange multiplier pattern $(Q^{\xi_l *}, \lambda^{s\xi_l *}, \lambda^{Q\xi_l *}, \lambda^{d\xi_l *}) \in \mathcal{K}^{\xi_l}$ is a multicommodity international trade network equilibrium under capacity disruptions in disasters, according to Definition 1, if and only if it satisfies the variational inequality:

$$\sum_{k=1}^{K}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{P}\Big[(\tilde{\pi}_i^k(Q^{\xi_l *}) + c_{ijr}^k(Q^{\xi_l *}))e_{ij}^{\xi_l} + \lambda_i^{s^k\xi_l *} + \lambda_{ijr}^{Q^k\xi_l *} + \lambda_j^{d^k\xi_l *} - \tilde{\rho}_j^k(Q^{\xi_l *})\Big]$$

$$\times (Q_{ijr}^{k\xi_l} - Q_{ijr}^{k\xi_l *})$$

$$+\sum_{k=1}^{K}\sum_{i=1}^{m}\Big[u_i^{s^k\xi_l} - \sum_{j=1}^{n}\sum_{r=1}^{P} Q_{ijr}^{k\xi_l *}\Big] \times (\lambda_i^{s^k\xi_l} - \lambda_i^{s^k\xi_l *})$$

$$+\sum_{k=1}^{K}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{P}\Big[u_{ijr}^{Q^k\xi_l} - Q_{ijr}^{k\xi_l *}\Big] \times (\lambda_{ijr}^{Q^k\xi_l} - \lambda_{ijr}^{Q^k\xi_l *})$$

$$+\sum_{k=1}^{K}\sum_{j=1}^{n}\Big[u_j^{d^k\xi_l} - \sum_{i=1}^{m}\sum_{r=1}^{P} Q_{ijr}^{k\xi_l *}\Big] \times (\lambda_j^{d^k\xi_l} - \lambda_j^{d^k\xi_l *}) \geq 0, \quad \forall (Q^{\xi_l}, \lambda^{s\xi_l}, \lambda^{Q\xi_l}, \lambda^{d\xi_l}) \in \mathcal{K}^{\xi_l}. \tag{5}$$

International Trade Network Performance Indicator

Definition 2: International Trade Network Performance Indicator Under Capacity and Exchange Rate Disruption ξ_l

For an international trade network $G = [N, L]$, where N is the set of nodes and L is the set of links, as depicted in Figure 1, and, given the underlying multicommodity supply price, unit transportation cost, and demand price functions, and exchange rates and capacities associated with disaster scenario ξ_l, we define the performance $\mathcal{E}^{\xi_l}$ as follows:

$$\mathcal{E}^{\xi_l}(G, \tilde{\pi}, c, \tilde{\rho}, u^{\xi_l}, e^{\xi_l}) = \frac{1}{Kn} \sum_{k=1}^{K} \sum_{j=1}^{n} \frac{d_j^{k\xi_l *}}{\hat{\rho}_j^k(Q^{\xi_l *})}, \quad (6)$$

where the demands and the incurred demand market prices are obtained through the solution of variational inequality (5) for the problem.

Unified International Trade Network Performance Measure

Definition 3: Unified International Trade Network Performance Measure

The performance indicator $\mathcal{E}$ *for an international trade network under disruption set* Ξ *and with associated probabilities* $p_{\xi_1}, p_{\xi_2}, \ldots, p_{\xi_\omega}$*, respectively, is defined as:*

$$\mathcal{E} = \sum_{l=1}^{\omega} \mathcal{E}^{\xi_l} p_{\xi_l}. \quad (7)$$

We let $\mathcal{E}^0$ *be the performance of the international trade network under its original (not disrupted) upper bounds/capacities and original exchange rates, such that:*

$$\mathcal{E}^0(G, \tilde{\pi}, c, \tilde{\rho}, u^0, e^0) = \frac{1}{Kn} \sum_{k=1}^{K} \sum_{j=1}^{n} \frac{d_j^{k*}}{\hat{\rho}_j^k(Q^*)}, \quad (8)$$

where u^0 *denotes the vector of original capacities not under disruptions and* e^0 *denotes the vector of exchange rates, also, not under disruptions. We refer to the expressions in (7) and (8) as "efficiency" measures.*

Robustness Measurement

Assessing Performance of International Trade Networks

Definition 4: Robustness of an International Trade Network Under Disruptions

The robustness, $\mathcal{R}$, of an international trade network under capacity and exchange rate disruptions is calculated as:

$$\mathcal{R} = \mathcal{E}^0 - \mathcal{E}. \tag{9}$$

According to the above definition, an international trade network is more robust if, under disruptions, its performance lies close to its performance in the absence of disruptions; that is, the closer the value of $\mathcal{R}$ is to 0.00, the more robust to disruptions the international trade network is.

Importance Indicator of an International Trade Network Component

Definition 5: Importance Indicator of an International Trade Network Component

The importance indicator of an international trade network component g where g can correspond to a supply market, a demand market, or a transportation route, or a combination thereof is defined as:

$$I(g) \equiv \frac{\mathcal{E}(G, \tilde{\pi}, c, \tilde{\rho}, u^0, e^0) - \mathcal{E}(G - g, \tilde{\pi}, c, \tilde{\rho}, u^0, e^0)}{\mathcal{E}(G, \tilde{\pi}, c, \tilde{\rho}, u^0, e^0)}, \qquad (10)$$

where $G - g$ denotes the graph with the component g no longer functioning.

Note that the international trade network component importance indicator (10) quantifies the relative efficiency/performance drop of the trade network when the component is no longer available.

Some of the Insights Gained

Numerical examples, drawn from the consequences of Russia's war on Ukraine, and focused on the agricultural trade of wheat and corn from Ukraine to MENA (Middle East and North Africa) countries; specifically, Lebanon and Egypt, were solved using an easy to implement algorithm to feature several disaster scenarios in addition to the baseline scenario.

Our results reinforce the importance of the maritime routes for the efficiency of this international trade network. For example, pre-war, Ukraine used to export more than 90% of its grains via maritime freight through its Black Sea ports.

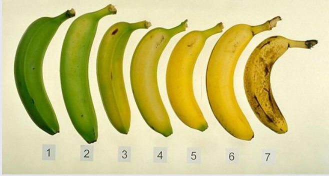
When we considered disruption scenarios of reduction to supply capacity, to transportation capacity, and to both, as in wartime, which are quite representative of the actual scenarios as the war on Ukraine by Russia has progressed for over 3 years, the international trade network considered here is not robust.

In various studies, focusing on international trade of wheat and corn, and with countries such as Ukraine, and MENA countries of Egypt and Lebanon, we have demonstrated:

- The impacts of the Black Sea disruptions on food insecurity in terms of prices and quantity of trade flows of wheat and corn;
- The importance of efficient, effective transportation routes that include maritime transport on the Black Sea;
- How subsidies can assist farmers in wartime;
- The effects of arable land reduction on crop planting decision-making;
- The importance of various transportation links (and their ranking), among other findings.

Some of the Insights Gained

Plus, our recent research has also investigated quantitatively the impacts of the drought in the Panama Canal on the banana trade to the US and Europe from South America, with the inclusion of quality deterioration due to time delays.



Making a Positive Impact

Writing OpEds

THE CONVERSATION

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

Author

Anna Nagurney

Partners

UMASS AMHERST

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

Chicago Tribune

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

By Anna Nagurney

(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

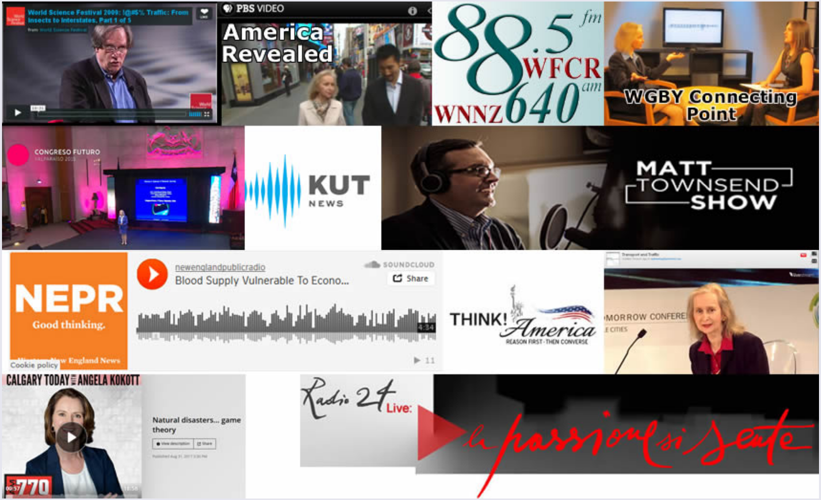
How disaster relief efforts could be improved with game theory

By Anna Nagurney

Published 13 March 2017

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

Coverage by the Media



Writing OpEds in the Pandemic

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

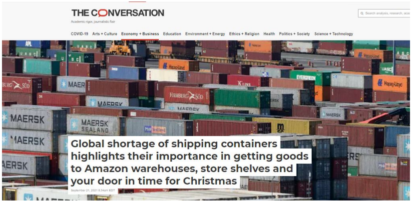
On August 4, 2020, I published an article in *The Conversation*,

"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."

Writing OpEds in the 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

IndustryWeek

IW INTELLIGENCE TALENT TECHNOLOGY & IIOT OPERATIONS LEADERSHIP

THE ECONOMY › COMPETITIVENESS

After One Year of War, How Is Ukraine Managing?

April 14, 2023

Signs of economic resilience include a functioning banking system and a thriving IT sector.

TheMessenger Opinion.

It's time to break the news.

OPINION

THE VIEWS EXPRESSED BY CONTRIBUTORS ARE THEIR OWN AND NOT THE VIEW OF THE MESSENGER

To Plant or Not to Plant? For Ukrainian Farmers, It's Life or Death

Published 06/11/23 09:30 AM ET | Updat

Anna Nagurney

Ukraine's Students

TO THE EDITOR:

Re "For Children of War, a Time for Play" (news article and photo essay, Aug. 8):

As children, their families and teachers get excited about the new school year throughout the world, it is imperative

ORMS TODAY informs membership magazine

Operations Research for the Recovery and Reconstruction of Ukraine

By Anna Nagurney

CHICAGO SUN-TIMES

OTHER VIEWS COMMENTARY

Ukraine will need 'Marshall Plan' to address human toll of war

C6 | THURSDAY, MAY 11, 2023 THE REPUBLICAN MASSLIVE.COM

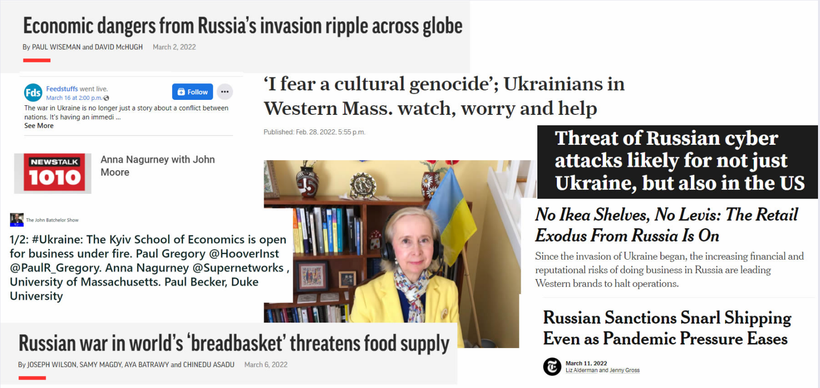
OPINION

LETTERS TO THE EDITOR

Scholars from Ukraine, UMass find common ground

Some of My Media Interviews in the Pandemic

Some of the Media Interviews on the War on Ukraine



Economic dangers from Russia's invasion ripple across globe

By PAUL WISEMAN and DAVID McHUGH March 2, 2022

Feedstuffs went live.
March 16 at 2:00 p.m.
Follow
The war in Ukraine is no longer just a story about a conflict between nations. It's having an immedi ...
See More

NEWSTALK 1010
Anna Nagurney with John Moore

The John Batchelor Show
1/2: #Ukraine: The Kyiv School of Economics is open for business under fire. Paul Gregory @HooverInst @PaulR_Gregory. Anna Nagurney @Supernetworks , University of Massachusetts. Paul Becker, Duke University

'I fear a cultural genocide'; Ukrainians in Western Mass. watch, worry and help

Published: Feb. 28, 2022, 5:55 p.m.

Threat of Russian cyber attacks likely for not just Ukraine, but also in the US

No Ikea Shelves, No Levis: The Retail Exodus From Russia Is On

Since the invasion of Ukraine began, the increasing financial and reputational risks of doing business in Russia are leading Western brands to halt operations.

Russian Sanctions Snarl Shipping Even as Pandemic Pressure Eases

March 11, 2022
Liz Alderman and Jenny Gross

Russian war in world's 'breadbasket' threatens food supply

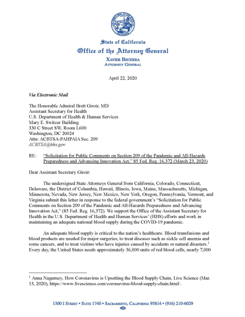
By JOSEPH WILSON, SAMY MAGDY, AYA BATRAWY and CHINEDU ASADU March 6, 2022

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.**

Impacting Policy



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, became the Secretary of Health and Human Services in the US under President Biden! Maura Healey, then the MA Attorney General, is now the Governor of Massachusetts.

Thank You Very Much!

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