Trade Wars and Game Theory: Who Wins, Who Loses?

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Gaylord National Resort & Convention Center
National Harbor, Maryland, April 12-14, 2026

Acknowledgments

Many thanks to INFORMS and to the organizers of this INFORMS Analytics+ Conference!

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

Outline of This Presentation

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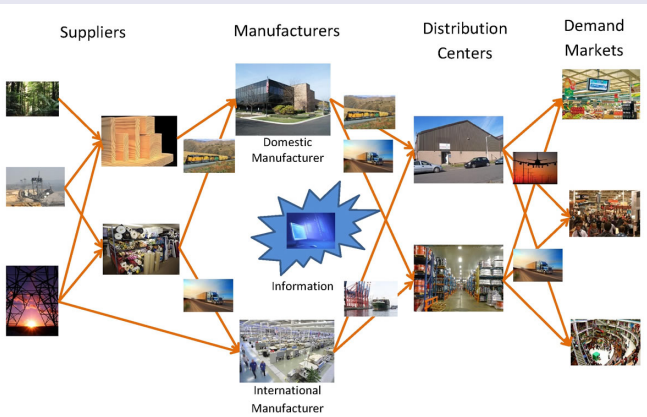
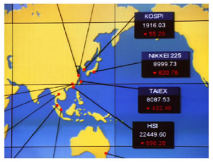
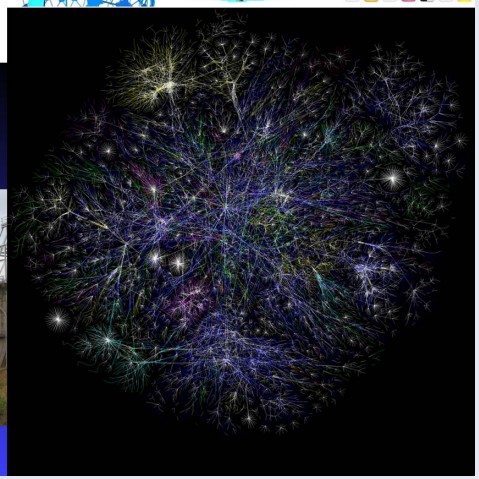
- **International Trade and Policies**
- **Some of Our Research on Tariffs and Trade Policies**
- **International Agricultural Trade and Policies**
- **Supply Chain Network Model with Labor and Tariffs**
- **Rerouting to Avoid Tariffs**
- **Some Related Recent Research**
- **Making a Positive Impact**

Background and Motivation

I Work on the Modeling of Network Systems



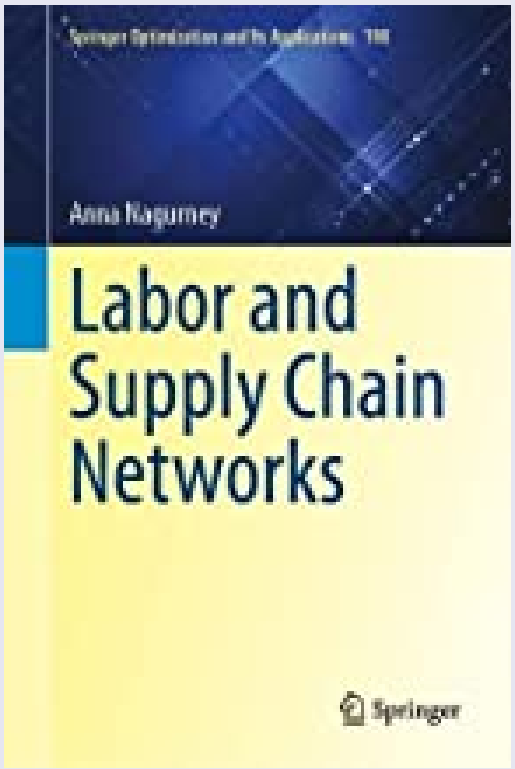


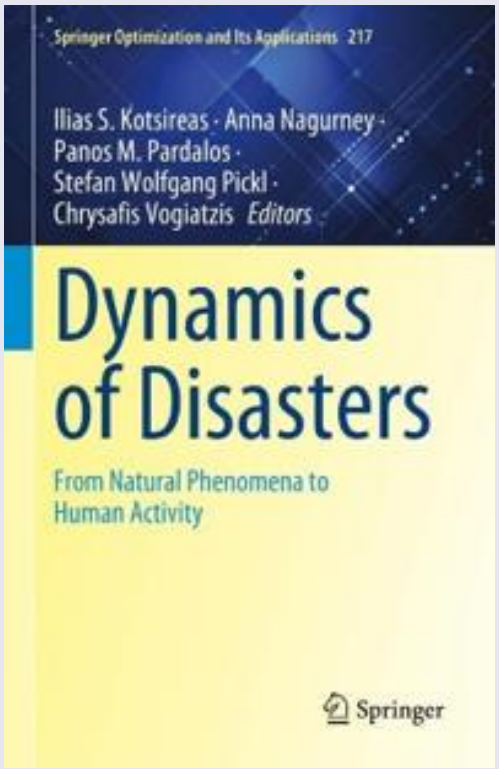


Much of My Recent Research Has Been on Supply Chains

Some of My Books

My Latest Books





International Trade and Policies

International Trade

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

World Trade Data - Top Exporters and Importers

Global Trade Policies

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

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.**

Some History of the US and Tariffs

The Tariff of 1789, signed by President George Washington, was one of the first laws passed by the new federal government, was as much about protection as it was about raising money. The tariff imposed duties on a wide range of imported goods and helped to pay down the young nation's war debts. There were both unit tariffs imposed as well as ad valorem tariffs.

- **An ad valorem tariff of 5% to 15% was imposed on most imported goods.**

- **A unit tariff was imposed on over 30 commodities including: coffee, tea, distilled spirits, cheese, cocoa, and molasses.**

Some History of the US and Tariffs

Smoot-Hawley Tariff Act of 1930, signed by President Hebert Hoover, raised tariffs on over 20,000 imported goods to protect farmers and industries during the Great Depression.

- **Most were unit tariffs, rather than ad valorem ones.**

However, it triggered retaliatory tariffs from trading partners, slashing global trade by 66% and deepening the economic crisis.

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!

Canada Newsroom United States

Trump's Proposed 25% Tariff on Canada and Mexico: Potential Impacts on Agriculture and Trade

By **Jim Eadie** - January 23, 2025

Tariffs on Canadian and Mexican Imports: The Impact on Agriculture

It should come as no surprise that Mexico and Canada are the top-two US agricultural export markets

PUBLISHED ON **JANUARY 29, 2025**

America's favorite beer, avocados, gas and cheap stuff from Temu will get more expensive as economists warn of Trump tariffs impact

By Ronny Reyes
Published Feb. 2, 2025, 6:29 p.m. ET

1.9K Comments

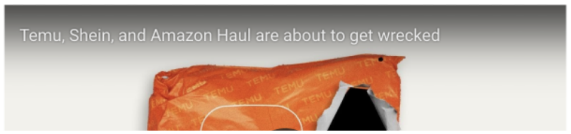
New Tariffs That Start Tomorrow Could Affect Farmers and Food Prices

The Trump administration will impose a 25 percent tariff on imports from Canada and Mexico, the U.S.' first and third largest suppliers of agricultural products.

BY LISA HELD • JANUARY 31, 2025

NEWS

Shipping companies warn of delays and new charges from Trump's China tariffs



/ Delays, taxes, a
– shipping from
just got more co

Trump's tariffs will hurt UK wherever they're imposed, says Bank

A global trade war would hit growth even if Britain is not a 'direct recipient' of the US president's levies on imports, the Bank of England governor says

• NEW

What might be the impact on agriculture of tariffs on Canadian and Mexican imports?

// BLOG // WHAT MIGHT BE THE IMPACT ON AGRICULTURE OF TARIFFS ON CANADIAN AND MEXICAN IMPORTS?

LOCAL NEWS

Colorado agriculture producers brace for tariff impacts

CBS NEWS COLORADO

By Olivia Young
February 3, 2025 / 7:01 AM MST / CBS Colorado

According to *The Economist*, April 4th-10th, 2026 Issue

President Donald Trump, on April 2, 2025, proclaimed "Liberation Day" in the White House Rose Garden, announcing a unilateral 10% tariff on almost all foreign imports, rising up to 50% for many countries. He invoked the International Emergency Economic Powers Act (IEEPA).

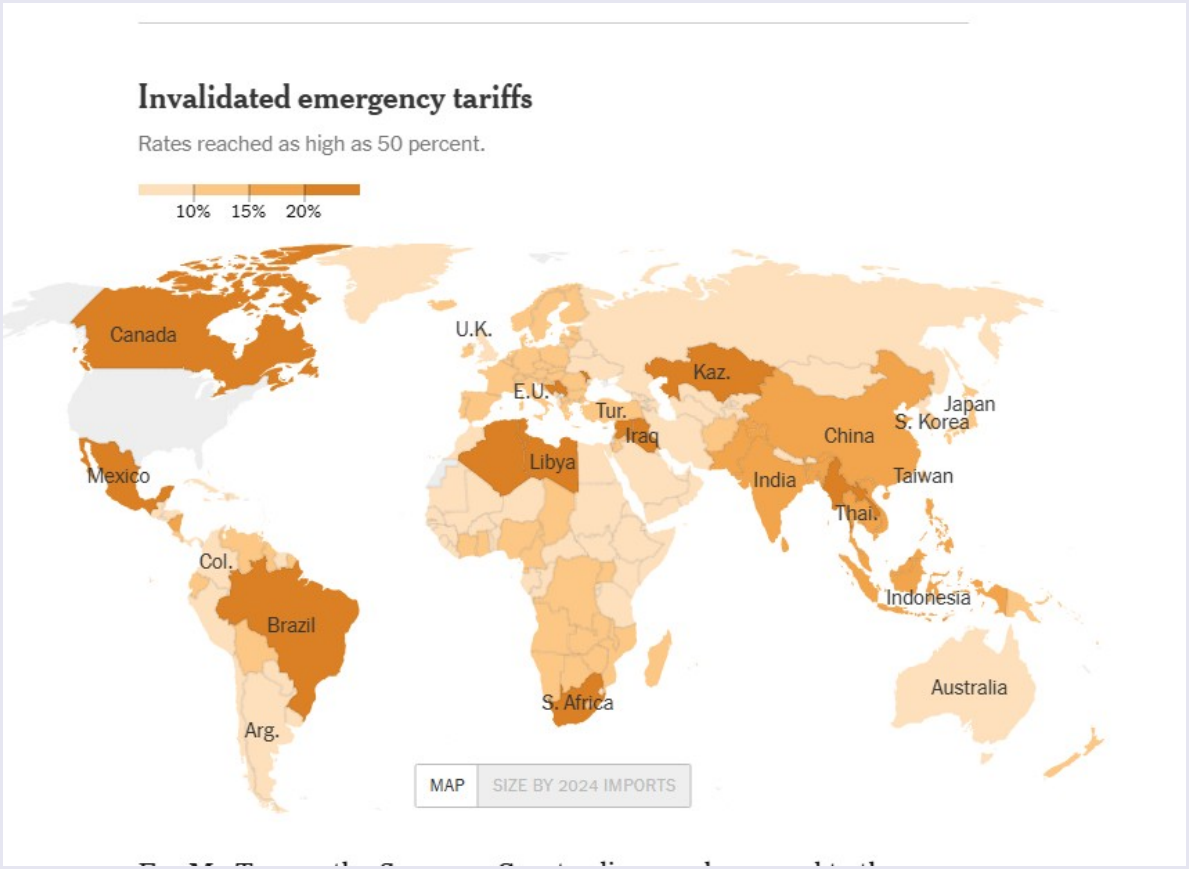
- The effective tariff rate in the US briefly topped 20%. Even after falling to 10.5% **it is at its highest since the 1940s.**

- **Between May and December 2025, real imports from China were over 40% lower than the same months in 2024**. The use of "real" implies that the figures are adjusted for price changes (inflation), showing a true, sharp reduction in physical volume of goods, not just a fluctuation in prices.

Supreme Court Decision on Tariffs on February 20, 2026

Chief Justice Roberts' paragraph from the majority opinion on President Trump lacking the authority he had claimed, under the International Emergency Economic Powers Act, to impose tariffs on countries all over the world: *Since imposing each set of tariffs, the president has issued several increases, reductions and other modifications.* **One month after imposing the 10 percent drug trafficking tariffs on Chinese goods, he increased the rate to 20 percent. One month later, he removed a statutory exemption for Chinese goods under $800. Less than a week after imposing the reciprocal tariffs, the president increased the rate on Chinese goods from 34 percent to 84 percent. The very next day, he increased the rate further still, to 125 percent. This brought the total effective tariff rate on most Chinese goods to 145 percent.** *The president has also shifted sets of goods into and out of the reciprocal tariff framework ([e.g.,] exempting from reciprocal tariffs beef, fruits, coffee, tea, spices and some fertilizers). And he has issued a variety of other adjustments ([e.g.,] extending "the suspension of heightened reciprocal tariffs" on Chinese imports.*

Invalidated Tariffs



According to *The New York Times*, the Supreme Court ruling marks an end to the tariffs President Trump announced last April on "Liberation Day." These tariffs were among his most punishing.

Revenue Collected by US from Invalidated Tariffs

The U.S. government collected over $130 billion to $166 billion in revenue from the invalidated Trump-era tariffs.

Estimates suggest that up to $175 billion in revenue, including interest, is now subject to potential refunds to businesses.

After Certain Tariffs Were Invalidated

- **President Trump invoked Section 122 of the Trade Act of 1974 to impose a 10% (potentially rising to 15%) global tariff on most imports, effective February 24, 2026. This temporary 150-day measure aims at countries with significant trade surpluses, while exempting certain goods not produced in the U.S. On Friday, April 10, 2026, the U.S. Court of International Trade, a specialized court in New York, heard oral arguments in an attempt to overturn these temporary tariffs.**

- **The administration continues to rely on Section 232 (national security) and Section 301 (unfair trade practices) to maintain or increase tariffs on specific goods, including 50% on steel/aluminum/copper and 25% on autos.**

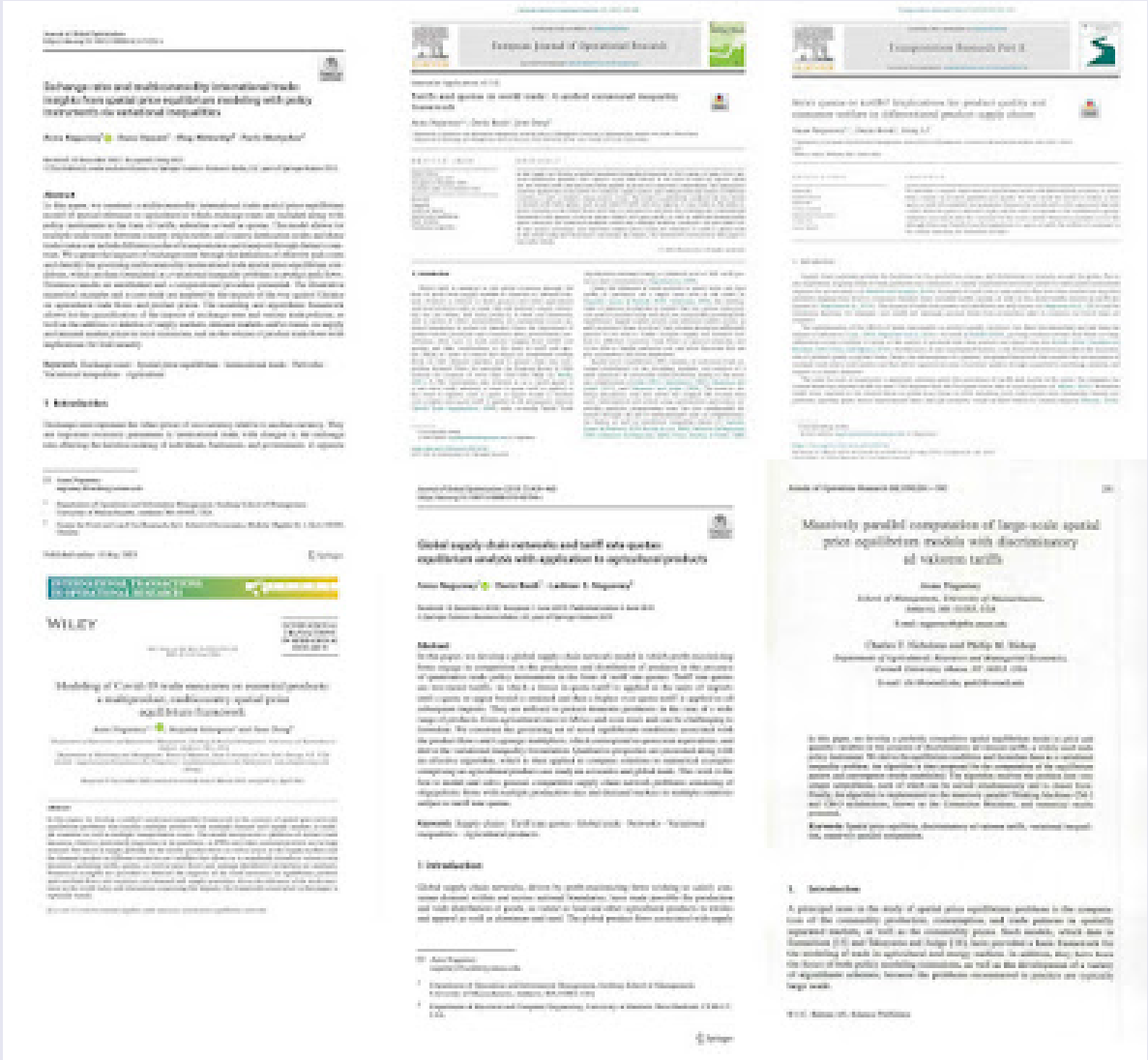
Global Trade Policies

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

This is very challenging research!

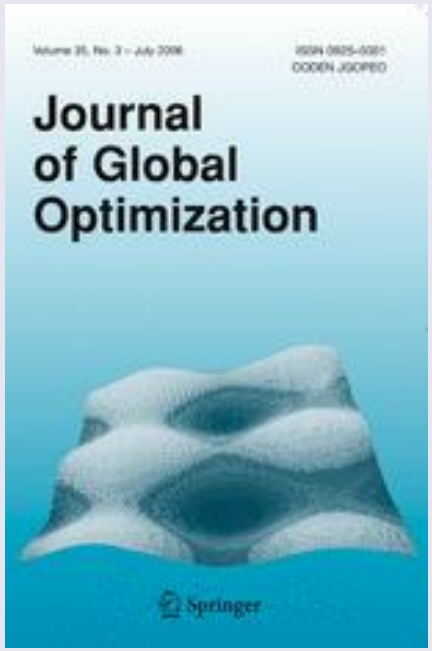
Some of Our Research on Tariffs and Trade Policies

Some of Our Papers on Tariffs and Other Policies



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.**



The model is a game theory one with tariff rate quotas and the numerical case study is on avocadoes.

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.**

The model is a spatial price equilibrium one with tariff rate quotas and the numerical case study is on the dairy industry.

Investigation of Tariffs and Quotas in the Pandemic

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.**

The model is a spatial price equilibrium one with unit tariffs, quotas, price floors, and ceilings. The case study is on N95 masks.

International Agricultural Trade and Policies

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.

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.

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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

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

Contents lists available at ScienceDirect

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

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ARTICLE INFO

Keywords:
Agricultural trade
Spatial price equilibrium
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 trade routes between country origin nodes and country destination nodes. The governing equilibrium conditions are then proposed. A series of numerical examples, both illustrative and realistically-derived and 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 of lack of investment in mitigation measures. Climate change is exacerbating the intensity of many disasters as well as the number of people affected by them. Disasters, both slow-onset and sudden-onset ones, can have an immense impact on nations, regions, businesses, organizations, and individuals and their families with long-lasting repercussions, including the escalation of economic and social costs.

A multiplicity of disasters can also impact food security. Even before Russia launched the full-scale invasion of Ukraine on February 24, 2022, climate change and COVID-19 had already impacted the 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 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. The reduction of lands used to harvest spring crops is projected at about 20%. Further exacerbated by the damaged production and storage facilities and the accessibility to essential inputs, such as seeds, fertilizer, fuel, etc., the decrease in Ukrainian cereal production is estimated at around 40% as compared to the output levels of 2021. In addition, there have been immense challenges in

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https://doi.org/10.1016/j.ejor.2023.11.010
Received 17 April 2023; Accepted 2 November 2023
Available online 7 November 2023
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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

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Received: August 20, 2021
Revised: February 25, 2024; July 11, 2024
Accepted: July 16, 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. Belgrave (2022) reports a rise of around 17%, in the population facing food insecurity worldwide because of the full-scale invasion, equivalent to an increase of 47 million human beings facing food security issues. According to Rose (2022), the disruptions in the exports of Ukrainian grain can cost the global economy more than 1.6 billion dollars.

The already strained food supply chains from the repercussions of the COVID-19 pandemic and climate change have been further hampered by the loss of arable land in Ukraine, known as the breadbasket of Europe, 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 have fly 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 exports from Ukraine (BBC 2022), caused a global shortage of grain and sky-rocketed global food prices (Wageningen University & Research 2022). The twice-extended Black Sea Grain Initiative), facilitated by Turkey and the United Nations, allowed for the limited passage of grain shipments from selected Ukrainian ports on the Black Sea from August 1, 2022, onward (UN News 2022). The initiative resulted in around 33 million tons of Ukrainian grain being shipped to other countries (Nicholls and Fasslabendridge 2023); however, the export levels remained significantly 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

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

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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.

Farmers are Dealing with Disasters on Top of Tariffs

- **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 and now we have the war on Iran with the Strait of Hormuz disrupted.**

Supply Chain Network Model with Labor and Tariffs

Impacts of Tariffs in Supply Chains on Labor

A. Nagurney and S. Samadi, "Ad Valorem Tariffs in Global Supply Chain Networks and Impacts on Labor," *Journal of the Operational Research Society* **(2025),** https://doi.org/10.1080/01605682.2025.2592758.

The model is a game theory one and the numerical case study is on soybeans.

The Global Supply Chain Network Topology

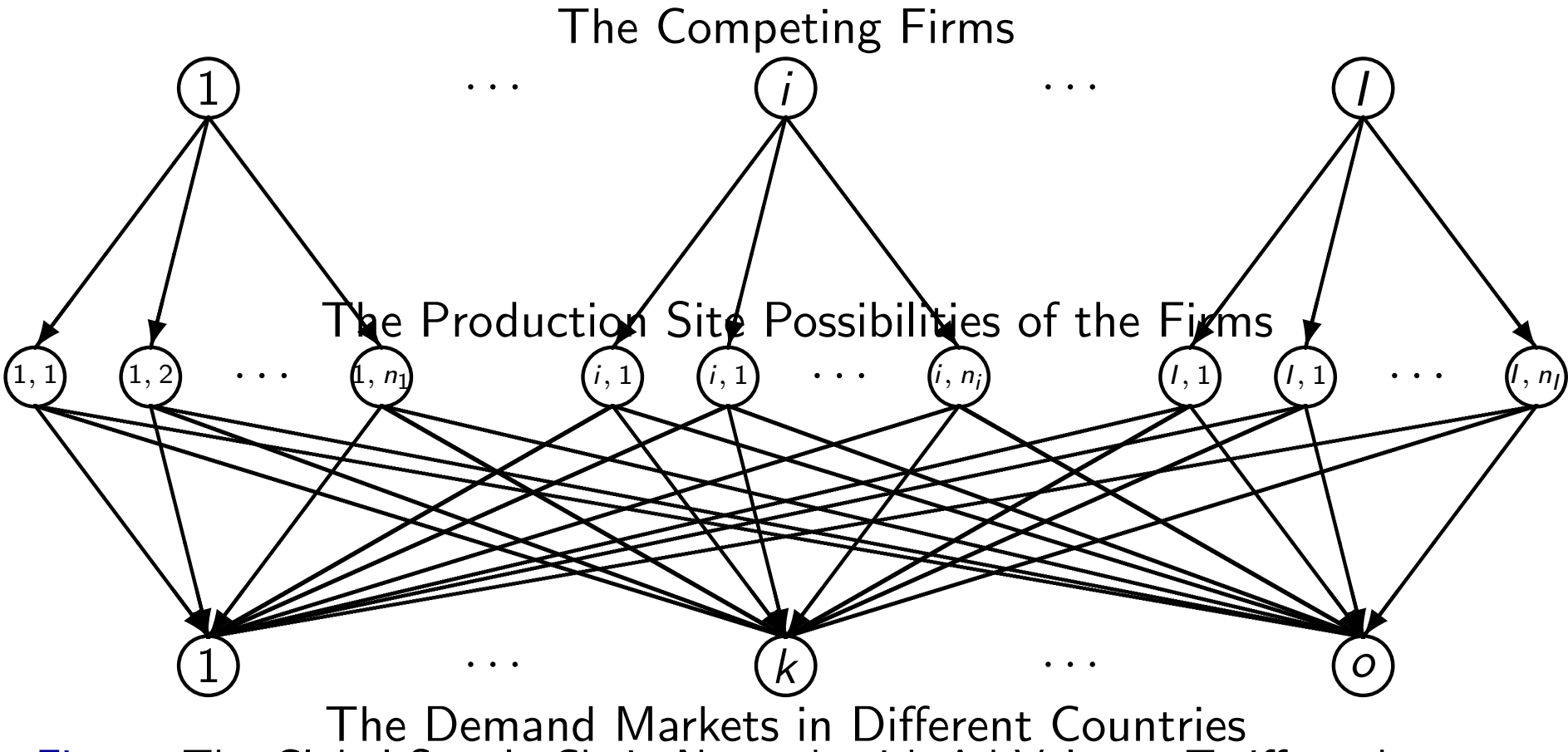


Figure: The Global Supply Chain Network with Ad Valorem Tariffs and Labor

Table: Notation for the Global Supply Chain Network Model with Tariffs

Variables	Definition
s_j^i	nonnegative production output (supply) of firm i at its production site j; $j = 1, \ldots, n_i$. Group outputs for each i; $i = 1, \ldots, I$, into vector $s^i \in R_+^{n_i}$ and all such vectors into $s \in R_+^{\sum_{i=1}^{I} n_i}$.
Q_{jk}^i	nonnegative amount of firm i's product produced at its site j and shipped to demand market k. The $\{Q_{jk}^i\}$ elements for all j and k are grouped into vector $Q^i \in R_+^{n_i o}$ and Q^i; $i = 1, \ldots, I$, into $Q \in R_+^{\sum_{i=1}^{I} n_i o}$.
d_k^i	demand for firm i's product at demand market k. Group demands for firm i's product for each $i = 1, \ldots, I$, into vector $d^i \in R_+^o$ and then group demands for all i into $d \in R_+^{Io}$.
l_j^i	labor (in hours) available at firm i's production site j; $i = 1, \ldots, I$; $j = 1, \ldots, n_i$.
l_{jk}^i	labor (in hours) available for shipping firm i's product for $i = 1, \ldots, I$ from its production site j; $j = 1, \ldots, n_i$ to market k; $k = 1, \ldots, o$.

Table: Notation for the Global Supply Chain Network Model with Tariffs

Functions	**Definition**
$f_j^i(s)$	production cost at firm i's site j.
$\hat{c}_{jk}^i(Q)$	total transportation cost associated with shipping firm i's product, produced at site j, to demand market k.
$\rho_k^i(d)$	demand price function for firm i's product at demand market k.

Table: Notation for the Global Supply Chain Network Model with Tariffs

Parameters	Definition
w_j^i	hourly wage at firm i's production site j.
w_{jk}^i	hourly wage for shipping firm i's product from its production site j to demand market k.
β_j^i	positive factor relating inputs of labor at firm i's production site j to the amount of product produced there.
β_{jk}^i	positive factor relating inputs of labor to shipment volume of firm i's product from its site j to market k.
$\bar{l}_j^i$	upper bound on labor hours of availability at production site j of firm i.
$\bar{l}_{jk}^i$	upper bound on labor hours of availability for shipment of firm i's product produced at its site j to market k.
τ_{jk}^i	ad valorem tariff rate between country that production site j of firm i is in and country of market k

Conservation of Flow Equations

The production output at firm i's site j, s_j^i, is equal to the total shipments of firm i's product to all the demand markets; that is:

$$s_j^i = \sum_{k=1}^{o} Q_{jk}^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i, \tag{1}$$

whereas the demand for firm i's product at demand market k, d_k^i, must be satisfied by the firm's product shipments from all the firm's production sites to each demand market; hence:

$$d_k^i = \sum_{j=1}^{n_i} Q_{jk}^i, \quad i = 1, \ldots, I; k = 1, \ldots, o. \tag{2}$$

Furthermore, all the product shipments must be nonnegative:

$$Q_{jk}^i \geq 0, \quad i = 1, \ldots, I; j = 1, \ldots, n_i; k = 1, \ldots, o. \tag{3}$$

Relationship Between Labor and Productivity

Using an approach as in Nagurney (2023a, b), relating labor to production outputs, as in economics, we have that the relationships, under the assumption of linearity between product outputs and labor, are at the production sites, and in transportation, respectively, as follows:

$$s_j^i = \beta_j^i l_j^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i, \tag{4}$$

and

$$Q_{jk}^i = \beta_{jk}^i l_{jk}^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i; k = 1, \ldots, o. \tag{5}$$

Also, the labor capacities cannot be exceeded, and the labor hours are nonnegative, so that

$$0 \leq l_j^i \leq \overline{l}_j^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i \tag{6}$$

and

$$0 \leq l_{jk}^i \leq \overline{l}_{jk}^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i; k = 1, \ldots, o. \tag{7}$$

Optimization Problems of the Competing Firms

Each firm i; $i = 1, \ldots, I$, seeks to maximize its utility, U^i, consisting of its net revenue, subject to its constraints. Therefore, the optimization problem faced by each firm i; $i = 1, \ldots, I$, is given by:

$$\text{Maximize } U^i = \sum_{j=1}^{n_i} \sum_{k=1}^{o} \frac{\rho_k^i(d) Q_{jk}^i}{(1+\tau_{jk}^i)} - \sum_{j=1}^{n_i} f_j^i(s) - \sum_{j=1}^{n_i} \sum_{k=1}^{o} \hat{c}_{jk}^i(Q)$$

$$- \sum_{j=1}^{n_i} w_j^i l_j^i - \sum_{j=1}^{n_i} \sum_{k=1}^{o} w_{jk}^i l_{jk}^i \qquad (8)$$

subject to: (1) – (7) for i.

The first term in (8) represents the revenue under the ad valorem tariff rate.

Some Reformulations

Because of expression (1), one can redefine the production cost functions (cf. Table 1) in terms of product shipments, thus:

$$\hat{f}_j^i = \hat{f}_j^i(Q) \equiv f_j^i(s), \quad i = 1, \ldots, I; j = 1, \ldots, n_i. \tag{9}$$

On the demand side, because of (2), one can redefine the demand price functions in terms of product shipments as:

$$\hat{\rho}_k^i = \hat{\rho}_k^i(Q) \equiv \rho_k^i(d), \quad i = 1, \ldots, I; k = 1, \ldots, o. \tag{10}$$

The production cost and the transportation cost functions are assumed to be convex and continuously differentiable and the demand price functions to be monotonically decreasing in demands, and continuously differentiable.

Some Reformulations

We will also replace the labor variables in the firms' objective functions with their product shipment equivalents. Towards that end, in view of (4) and (1), we have that:

$$\frac{\sum_{k=1}^{o} Q_{jk}^{i}}{\beta_j^i} = l_j^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i. \tag{11}$$

Also, in view of (5), we have that

$$\frac{Q_{jk}^{i}}{\beta_{jk}^i} = l_{jk}^i, \quad i = 1, \ldots, I; j = 1, \ldots, n_i; k = 1, \ldots, o. \tag{12}$$

Optimization Problems in Production Shipment Variables

$$\text{Maximize} \quad \hat{U}^i(Q) = \sum_{j=1}^{n_i}\sum_{k=1}^{o}\frac{\hat{\rho}_k^i(Q)Q_{jk}^i}{(1+\tau_{jk}^i)} - \sum_{j=1}^{n_i}\hat{f}_j^i(Q) - \sum_{j=1}^{n_i}\sum_{k=1}^{o}\hat{c}_{jk}^i(Q)$$

$$-\sum_{j=1}^{n_i} w_j^i \frac{\sum_{k=1}^{o} Q_{jk}^i}{\beta_j^i} - \sum_{j=1}^{n_i}\sum_{k=1}^{o} w_{jk}^i \frac{Q_{jk}^i}{\beta_{jk}^i} \tag{13}$$

subject to:

$$\frac{\sum_{k=1}^{o} Q_{jk}^i}{\beta_j^i} \leq \overline{l}_j^i, \quad j = 1, \ldots, n_i, \tag{14}$$

$$\frac{Q_{jk}^i}{\beta_{jk}^i} \leq \overline{l}_{jk}^i, \quad j = 1, \ldots, n_i; k = 1, \ldots, o, \tag{15}$$

$$Q_{jk}^i \geq 0, \quad j = 1, \ldots, n_i; k = 1, \ldots, o. \tag{16}$$

The utility functions of all the firms are assumed to be concave and continuously differentiable.

We define the feasible sets:

$$K^i \equiv \{Q^i | Q^i \text{ satisfies } (14) - (16)\}, \quad i = 1, \ldots, I \tag{17a}$$

and

$$K \equiv \prod_{i=1}^{I} K^i. \tag{17b}$$

Nash Equilibrium Conditions

Definition 1: Global Supply Chain Network Nash Equilibrium Under Ad Valorem Tariffs

A product shipment pattern $Q^* \in K$ is a global supply chain network Nash Equilibrium under ad valorem tariffs if, for each firm i; $i = 1, \ldots, I$, the following equilibrium condition holds:

$$\hat{U}^i(Q^{i*}, Q^{-i*}) \geq \hat{U}^i(Q^i, Q^{-i*}), \quad \forall Q^i \in K^i, \tag{18}$$

where $Q^{-i*} \equiv (Q^{1*}, \ldots, Q^{i-1*}, Q^{i+1*}, \ldots, Q^{I*})$.

According to (18), a Nash Equilibrium is established if no firm, unilaterally, with its selected strategies, can improve upon its utility, given the strategies of the other firms.

Theorem 1: Variational Inequality Formulation of the Global Supply Chain Network Nash Equilibrium Under Ad Valorem Tariffs

A product shipment pattern $Q^* \in K^i$ is a global supply chain network Nash Equilibrium under ad valorem tariffs according to Definition 1 if and only if it satisfies the variational inequality:

$$-\sum_{i=1}^{I}\sum_{j=1}^{n_i}\sum_{k=1}^{o}\frac{\partial \hat{U}^i(Q^*)}{\partial Q^i_{jk}} \times (Q^i_{jk} - Q^{i*}_{jk}) \geq 0, \quad \forall Q \in K. \qquad (19)$$

Theorem 2: Alternative Variational Inequality Formulations

VI (19) is equivalent to solving: determine
$(Q^*, \lambda^*, \mu^*, \epsilon^*) \in R_+^{\sum_{i=1}^{I} n_i o} + R_+^{\sum_{i=1}^{I} n_i} + R_+^{2\sum_{i=1}^{I} n_i o}$ *such that:*

$$\left[-\sum_{i=1}^{I} \sum_{j=1}^{n_i} \sum_{k=1}^{o} \frac{\partial \hat{U}^i(Q^*)}{\partial Q_{jk}^i} + \frac{\lambda_j^{i*}}{\beta_j^i} + \frac{\mu_{jk}^{i*}}{\beta_{jk}^i} - \epsilon_{jk}^{i*} \right] \times \left[Q_{jk}^i - Q_{jk}^{i*} \right]$$

$$+ \sum_{i=1}^{I} \sum_{j=1}^{n_i} \left[\overline{l}_j^i - \frac{\sum_{k=1}^{o} Q_{jk}^{i*}}{\beta_j^i} \right] \times \left[\lambda_j^i - \lambda_j^{i*} \right]$$

$$+ \sum_{i=1}^{I} \sum_{j=1}^{n_i} \sum_{k=1}^{o} \left[\overline{l}_{jk}^i - \frac{Q_{jk}^{i*}}{\beta_{jk}^i} \right] \times \left[\mu_{jk}^i - \mu_{jk}^{i*} \right] + \sum_{i=1}^{I} \sum_{j=1}^{n_i} \sum_{k=1}^{o} Q_{jk}^{i*} \times \left[\epsilon_{jk}^i - \epsilon_{jk}^{i*} \right] \geq 0,$$

$$\forall (Q, \lambda, \mu, \epsilon) \in R_+^{\sum_{i=1}^{I} n_i o + \sum_{i=1}^{I} n_i + 2\sum_{i=1}^{I} n_i o}. \qquad (20)$$

Alternative Variational Inequality Formulations

Or simplified as: determine $(Q^*, \lambda^*, \mu^*) \in R_+^{2\sum_{i=1}^{I} n_i o + \sum_{i=1}^{I} n_i}$ *such that:*

$$\left[-\sum_{i=1}^{I} \sum_{j=1}^{n_i} \sum_{k=1}^{o} \frac{\partial \hat{U}^i(Q^*)}{\partial Q_{jk}^i} + \frac{\lambda_j^{i*}}{\beta_j^i} + \frac{\mu_{jk}^{i*}}{\beta_{jk}^i} \right] \times \left[Q_{jk}^i - Q_{jk}^{i*} \right]$$

$$+ \sum_{i=1}^{I} \sum_{j=1}^{n_i} \left[\bar{l}_j^i - \frac{\sum_{k=1}^{o} Q_{jk}^{i*}}{\beta_j^i} \right] \times \left[\lambda_j^i - \lambda_j^{i*} \right]$$

$$+ \sum_{i=1}^{I} \sum_{j=1}^{n_i} \sum_{k=1}^{o} \left[\bar{l}_{jk}^i - \frac{Q_{jk}^{i*}}{\beta_{jk}^i} \right] \times \left[\mu_{jk}^i - \mu_{jk}^{i*} \right] \geq 0,$$

$$\forall (Q, \lambda, \mu) \in R_+^{2\sum_{i=1}^{I} n_i o + \sum_{i=1}^{I} n_i}. \qquad (21)$$

Numerical Examples: Soybeans

- Soybeans are a leading agricultural commodity in global trade, widely used in livestock feed, plant-based foods, and biofuels, with the market valued at USD 169.65 billion in 2024 and projected to reach USD 255.39 billion by 2033.

- Global soybean trade is highly concentrated, with Brazil, the United States, and Argentina as leading exporters and China as the dominant importer, making the market particularly sensitive to tariff policies such as those observed during the 2018 US–China trade conflict.

What Happened to US Soybean Farmers in 2025

- US soybean purchases by China fell sharply in 2025: after halting imports at the end of May, China resumed buying in November, but purchases totaled only $21.83 million, more than 99% below November 2024 levels.
- Tariffs shifted China's soybean imports toward South America, causing billions of dollars in lost sales for US soybean farmers.
- The US government announced about $11 billion in Farmer Bridge Payments to support farmers, including soybean producers, affected by temporary trade disruptions and rising production costs.
- Increased immigration crackdowns has created significant labor shortages in US agriculture, where about 40% of farmworkers are undocumented.

Network Topology

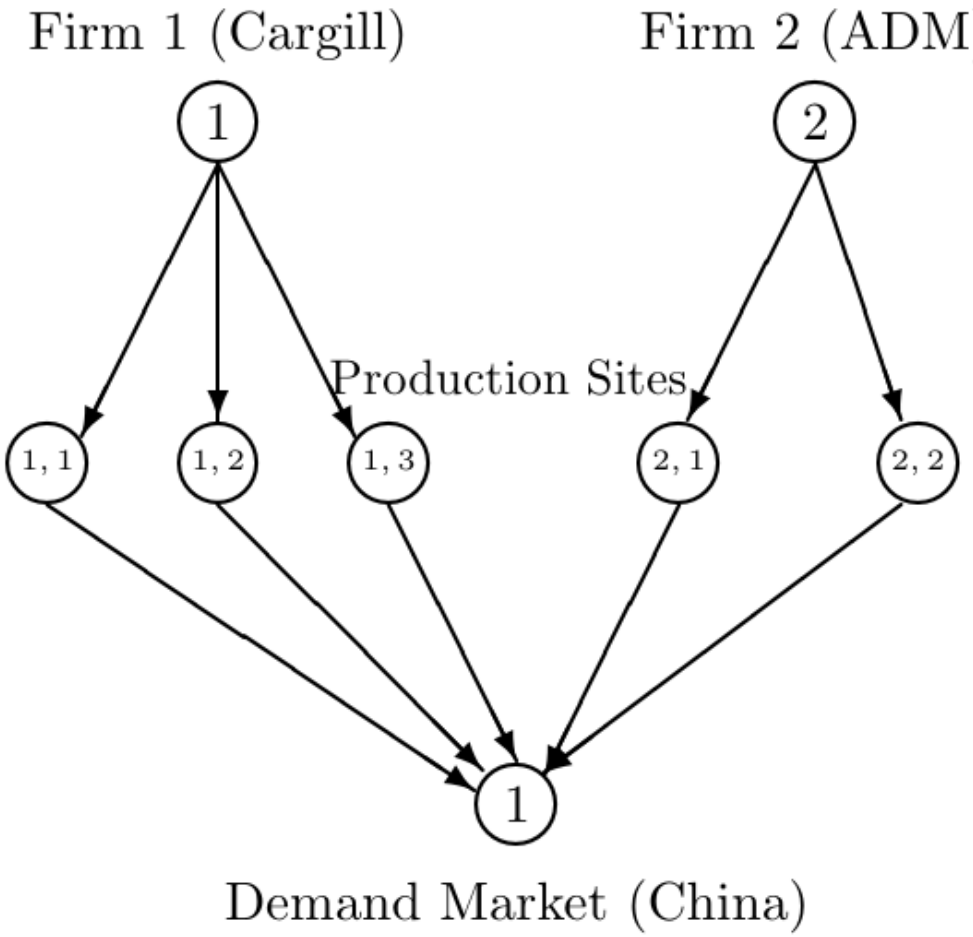


Figure: The Soybean Supply Chain Network Topology for Examples 1, 2, 3, and 4

Example 1: No Ad Valorem Tariffs - Data

- **Two firms representing major US soybean exporters (stylized versions of Cargill and ADM). Firm 1 operates three production sites (US, Brazil, Argentina), while Firm 2 operates two (US, Brazil).**
- **The single demand market represents China, the world's largest soybean importer.**
- **Labor wages differ by country: highest in the US and lower in Brazil and Argentina.**
- **Ad valorem tariffs are zero: $\tau_{jk}^{i} = 0$.**
- **Labor productivity parameters and upper bounds:**

$$\beta_{j}^{i} = 0.7, \forall i, j, \quad \beta_{jk}^{i} = 0.7, \forall i, j, k,$$

$$\overline{l}_{jk}^{i} = 3 \times 10^{7}, \forall i, j, k,$$

$$\overline{l}_{2}^{1} = \overline{l}_{2}^{2} = 3 \times 10^{7}, \quad \overline{l}_{1}^{1} = \overline{l}_{3}^{1} = \overline{l}_{1}^{2} = 2 \times 10^{7}.$$

Example 1: No Ad Valorem Tariffs - Functions

Production Costs

$$\hat{f}_1^1(Q) = 10^{-5}{Q_{11}^1}^2 + 90, \quad \hat{f}_2^1(Q) = 4.3 \times 10^{-6}{Q_{21}^1}^2 + 80,$$

$$\hat{f}_3^1(Q) = 7.3 \times 10^{-5}{Q_{31}^1}^2 + 100, \quad \hat{f}_1^2(Q) = 1.8 \times 10^{-5}{Q_{11}^2}^2 + 90,$$

$$\hat{f}_2^2(Q) = 9 \times 10^{-6}{Q_{21}^2}^2 + 80.$$

Transportation Costs

$$\hat{c}_{11}^1(Q) = 2 \times 10^{-5}{Q_{11}^1}^2 + 40, \quad \hat{c}_{21}^1(Q) = 5 \times 10^{-6}{Q_{21}^1}^2 + 30,$$

$$\hat{c}_{31}^1(Q) = 6 \times 10^{-5}{Q_{31}^1}^2 + 45, \quad \hat{c}_{11}^2(Q) = 10^{-5}{Q_{11}^2}^2 + 30,$$

$$\hat{c}_{21}^2(Q) = 4 \times 10^{-6}{Q_{21}^2}^2 + 15.$$

Demand Prices

$$\rho_1^1(d) = -1.8 \times 10^{-5}d_1^1 - 10^{-5}d_1^2 + 950,$$

$$\rho_1^2(d) = -10^{-5}d_1^1 - 2.5 \times 10^{-5}d_1^2 + 1050.$$

Discussion of Results: Example 1

- **Exports from Brazilian production sites exceed those from US sites, consistent with observed global soybean trade patterns and the real-world trade shares of major firms such as Cargill and ADM.**
- **Labor allocation follows production scale, with the largest number of workers employed at Brazilian production sites.**
- **Demand prices in China are \$531.16 per ton for Firm 1 and \$569.77 per ton for Firm 2, both broadly consistent with observed soybean import price of \$463.**
- **Firm 1 earns higher profits due to its larger production scale, and all Lagrange multipliers associated with labor constraints are zero, indicating that no labor constraints bind at equilibrium.**

Example 2: China's Retaliatory Ad Valorem Tariff on US Soybean Exports

• **In Example 2, the data are the same as in Example 1 except that we now examine the impact of a newly imposed 25% ad valorem tariff by China on US soybean imports, announced in April 2025 in direct response to US tariff measures earlier that month.**

• **The supply chain network structure remains as in Example 1, but we incorporate an ad valorem tariff rate on shipments from US production sites of both firms:**

$$\tau_{11}^1 = \tau_{11}^2 = 0.25.$$

Discussion of Results: Example 2

- **A 25% Chinese tariff rate reduces the competitiveness of US soybean exports, causing shipments from US sites to decline and shifting production toward Brazil and Argentina.**
- **For Firm 1, exports from the US site drop by 22.26%, while shipments from the US site for Firm 2 decline by 20.44%.**
- **Demand prices in China increase as total soybean supply declines, reaching \$536.62 and \$577.10 per ton for the two firms.**
- **Labor hours fall at US production sites and on transportation routes but rise in Brazil and Argentina.**
- **Profits decline for both firms, by 3.64% for Firm 1 and by 5.76% for Firm 2, despite the reallocation of production.**
- All Lagrange multipliers remain zero in this example.

Who Wins, Who Loses?

- **Producers in countries that tariffs on goods are imposed on generally have lower profits because of tariffs.**

- **Consumers can expect higher prices on products in countries that tariff products and a lower volume of the products. This is especially concerning in terms of agricultural products and can lead to heightened food insecurity.**

Example 3: Immigration Policy and its Impact on Available Labor at the US Production Sites

- **Example 3 has the same data as that in Example 1, except that we now examine the impact of the current farm labor shortage in the US due to increased immigration enforcement.**

- **In 2025, intensified immigration enforcement and the failure to renew working authorizations led to an estimated 70% of the agricultural workforce in key regions, especially California, stopping work.**

- **To simulate the labor shortage, we reduce the available labor hours at both firms' US production sites to $\bar{l}_1^1 = \bar{l}_1^2 = 2 \times 10^6$ hours.**

Discussion of Results: Example 3

- **Reduced labor availability at US production sites significantly disrupts soybean output for both firms.**
- **US shipments decline sharply: by 54.32% for Firm 1 and 59.95% for Firm 2, with labor constraints binding at the US sites.**
- **Positive Lagrange multipliers ($\lambda_1^{1*} = 85.10$, $\lambda_1^{2*} = 108.28$) indicate that the labor upper bounds are binding.**
- **Both firms reallocate production towards Brazil and Argentina, increasing shipments and labor usage at these sites and their associated transportation routes.**
- **Demand declines slightly while demand prices increase to \$545.31 and \$590.51 per ton.**
- **Profits change, but modestly, due to international production reallocation.**

Example 4: Combined Impact of Ad Valorem Tariffs Imposed on US and Brazilian Drought-Induced Production Cost Increases

- **Example 4 has the same data as Example 1, except we consider two shocks:**
  - **China imposes a 25% ad valorem tariff rate on US soybean imports:**

$$\tau_{11}^1 = \tau_{11}^2 = \mathbf{0.25}.$$

  - **Drought conditions in Brazil increase production costs at Brazilian sites:**

New Production Cost Functions at Brazilian Sites

$$\hat{f}_2^1(Q) = 7 \times 10^{-6}(Q_{21}^1)^2 + 150, \quad \hat{f}_2^2(Q) = 1.3 \times 10^{-5}(Q_{21}^2)^2 + 150.$$

Discussion of Results: Example 4

- **The combined shock of a 25% ad valorem tariff and higher Brazilian production costs reallocates global soybean trade flows.**
- **US exports increase relative to Example 2 but remain below the Example 1 as firms partially shift production back to the US.**
- **Brazilian exports decline by 7% at both firms, due to higher production costs, while Argentine shipments increase by 19.06% relative to Example 1.**
- **Labor allocation follows the same pattern: declining in Brazil, increasing in Argentina, with US labor higher than in Example 2 and lower than Example 1.**
- **Demand prices reach their highest levels, \$557.20 and \$600.36, while demands and profits fall to their lowest levels.**
- **All Lagrange multipliers remain zero.**

Results - Equilibrium Product Flows and Labor Hours at the Production Sites and Transportation Routes

	Example 1	Example 2	Example 3	Example 4
Q_{11}^{1*}	3,065,167.00	2,382,688.56	1,400,000.00	2,850,274.69
Q_{21}^{1*}	12,268,105.34	12,736,900.30	13,433,546.57	11,332,297.71
Q_{31}^{1*}	863,239.02	896,019.96	944,735.71	1,027,857.05
Q_{11}^{2*}	3,496,410.27	2,781,649.05	1,400,000.00	3,331,122.34
Q_{21}^{2*}	9,234,026.64	9,728,068.38	10,668,295.98	8,570,370.78
l_{11}^{1*}	4,378,810.01	3,403,840.80	2,000,000.00	4,071,820.99
l_{21}^{1*}	17,525,864.77	18,195,571.86	19,190,780.81	16,188,996.73
l_{31}^{1*}	1,233,198.61	1,280,028.51	1,349,622.44	1,468,367.22
l_{11}^{2*}	4,994,871.82	3,973,784.35	2,000,000.00	4,758,746.20
l_{21}^{2*}	13,191,466.63	13,897,240.55	15,240,422.83	12,243,386.84
l_{1}^{1*}	4,378,810.01	3,403,840.80	2,000,000.00	4,071,820.99
l_{2}^{1*}	17,525,864.77	18,195,571.86	19,190,780.81	16,188,996.73
l_{3}^{1*}	1,233,198.61	1,280,028.51	1,349,622.44	1,468,367.22
l_{1}^{2*}	4,994,871.82	3,973,784.35	2,000,000.00	4,758,746.20
l_{2}^{2*}	13,191,466.63	13,897,240.55	15,240,422.83	12,243,386.84

Results - Demand Prices, Demands, and Profits

	Example 1	**Example 2**	**Example 3**	**Example 4**
d_1^{1*}	16,196,511.37	16,015,608.82	15,778,282.28	15,210,429.45
d_1^{2*}	12,730,436.91	12,509,717.43	12,068,295.98	11,901,493.13
$\hat{\rho}_1^1$	531.16	536.62	545.31	557.20
$\hat{\rho}_1^2$	569.77	577.10	590.51	600.36
$\hat{U}^1$	6,502,623,987.76	6,265,508,717.39	6,507,263,407.57	5,933,698,880.38
$\hat{U}^2$	5,502,368,550.04	5,185,244,846.39	5,392,080,170.32	4,902,279,307.20

Additional Insights from Our Research

- **Specifically, from the consumer's perspective, the results consistently and unanimously show that consumer welfare declines for consumers in the country imposing a strict quota or tariff on an imported product. Hence, a government may wish to loosen a quota (equivalently, reduce a tariff) so as not to adversely affect its own consumers.**

- **Producing firms, as also critical stakeholders in competitive supply chain networks, should expand their demand markets within their own countries. This allows for a basic, but, effective, redesign of the supply chain network under a tariff or quota and results in higher profits for the firms.**

- **Also, firms should expand the number of production sites to countries not under a tariff or quota to maintain or improve upon their profits if some of their production sites are in countries subject to such trade policy instruments.**

What Our Research Has Shown

Whether in the context of supply chain networks under oligopolistic (imperfect) competition or perfect competition, our studies reveal that tariffs:

- increase prices for consumers;
- reduce the volume of the product;
- decrease consumer welfare;
- reduce profits for producers (unless new markets and production sites can be identified), and
- they can result in the same impacts as that of quotas.

Tariffs can, however, offer some protection to domestic producers but one has to evaluate whether this will happen quantitatively through OR models.

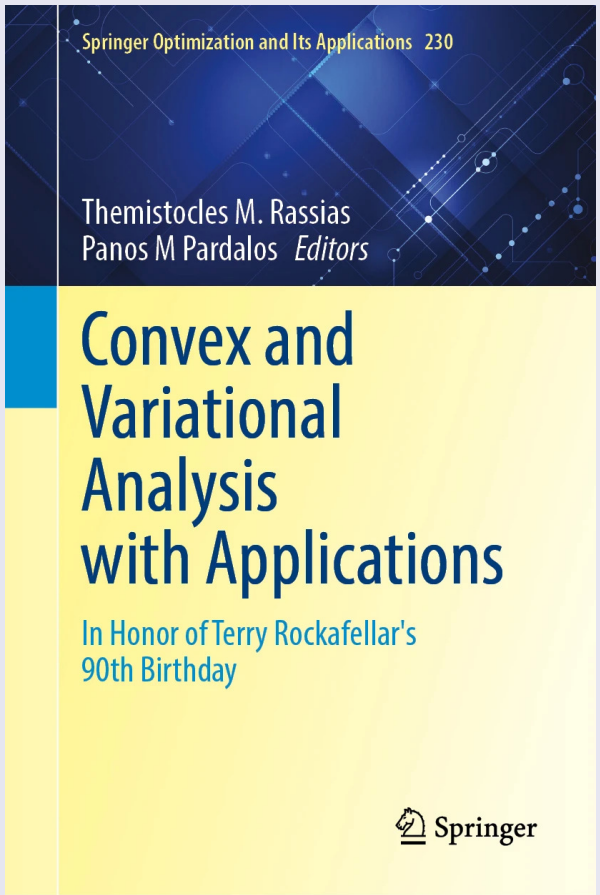
Rerouting to Avoid Tariffs

Producers' Reactions to Tariffs

- Producing countries (and firms therein) have responded to tariffs in additional ways including through nearshoring; that is, moving production closer, or onshoring (producing within one's country).
- Another response is rerouting products through third countries, with alteration of the origin country through documentation and without substantive addition of value to the products, a practice that, although illegal, may happen and the economic trade-offs are worth quantifying and exploring.

Our Paper

The paper, "Multicommodity Trade, Tariffs, and Rerouting," A. Nagurney and S. Samira, is in press in the (2026) book in honor of Terry Rockafellar.



Contributions

- In this paper, we introduce a new multicommodity trade model based on spatial price equilibrium in which multicommodity tariffs can be imposed by destination countries on the commodities based on their country of origin. Through the introduction of path tariffs we are able to identify equilibrium conditions that allow for the rerouting of commodities in order to evade tariffs.

- We allow for multiple trade routes; that is, paths, between country origin nodes and country destination nodes, and these paths can consist of one or more links.

- The links, in turn, in the case of rerouting of the commodity through countries to evade a tariff, can correspond to transportation links or repackaging/reprocessing links. For the sake of generality, we consider links to be transaction links, with associated costs.

Some Highlights from Our Rerouting Study

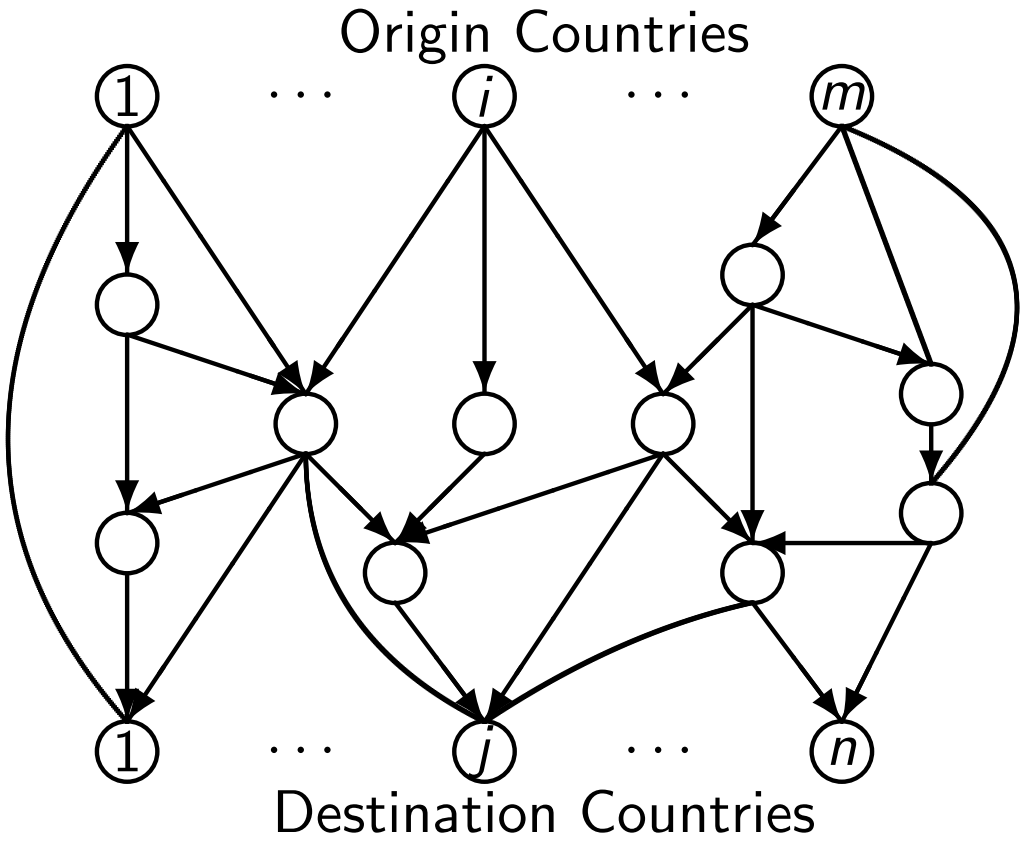


Figure: An Example of a Spatial Price Network Topology with Origin Countries and Destination Countries

Some Highlights from Our Rerouting Study

• We present both illustrative examples and algorithmically solved ones using the modified projection method, which expand on the former examples. **The application is that of trade of tea from China with rerouting through Vietnam.**

• The results reinforce, in part, what we have found in the context of agricultural trade from Ukraine in wartime - that having alternative trade routes is beneficial.

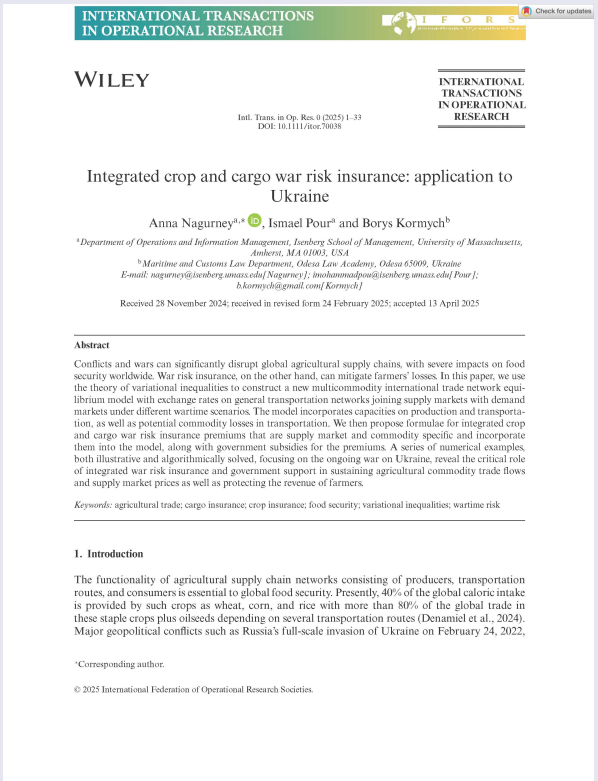
• **The results also reinforce that consumers in the country imposing a tariff lose in terms of the higher demand price, and the lower volume of commodity shipment.**

• Producers in the country whose product is tariffed, also lose, since the supply market price decreases.

Some Related Recent Research

Some Related Recent Research

In addition to tariffs and impacts, our recent research has also involved the modeling and calculation of integrated crop and cargo war risk insurance.



INTERNATIONAL TRANSACTIONS IN OPERATIONAL RESEARCH

WILEY

Intl. Trans. in Op. Res. 0 (2025) 1–33
DOI: 10.1111/itor.70038

Integrated crop and cargo war risk insurance: application to Ukraine

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Received 28 November 2024; received in revised form 24 February 2025; accepted 13 April 2025

Abstract

Conflicts and wars can significantly disrupt global agricultural supply chains, with severe impacts on food security worldwide. War risk insurance, on the other hand, can mitigate farmers' losses. In this paper, we use the theory of variational inequalities to construct a new multicommodity international trade network equilibrium model with exchange rates on general transportation networks joining supply markets with demand markets under different wartime scenarios. The model incorporates capacities on production and transportation, as well as potential commodity losses in transportation. We then propose formulae for integrated crop and cargo war risk insurance premiums that are supply market and commodity specific and incorporate them into the model, along with government subsidies for the premiums. A series of numerical examples, both illustrative and algorithmically solved, focusing on the ongoing war on Ukraine, reveal the critical role of integrated war risk insurance and government support in sustaining agricultural commodity trade flows and supply market prices as well as protecting the revenue of farmers.

Keywords: agricultural trade; cargo insurance; crop insurance; food security; variational inequalities; wartime risk

1. Introduction

The functionality of agricultural supply chain networks consisting of producers, transportation routes, and consumers is essential to global food security. Presently, 40% of the global caloric intake is provided by such crops as wheat, corn, and rice with more than 80% of the global trade in these staple crops plus oilseeds depending on several transportation routes (Denamiel et al., 2024). Major geopolitical conflicts such as Russia's full-scale invasion of Ukraine on February 24, 2022,

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The numerical case study is on wheat and corn trade.

Some Related Recent Research

Plus, we have been modeling quality impacts on fresh produce of capacity disruptions and transportation delays in international trade.

Journal of Global Optimization
https://doi.org/10.1007/s10898-025-01507-3

Multicommodity fresh produce trade networks with quality deterioration under congestion and transportation capacities

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Received: 8 October 2024 / Accepted: 22 May 2025

Abstract
This paper constructs a multicommodity spatial price equilibrium framework designed to allow for the quantification of the impacts of congestion and transportation capacities on trade flows and product prices while capturing the degradation of fresh produce quality through explicit quality deterioration formulas. We present the multicommodity fresh produce trade network model under equilibrium conditions both without and with minimum quality standards. Alternative variational inequality formulations of the governing equilibrium conditions are derived, with one of them exhibiting particularly favorable features for computational purposes. The numerical examples focus on the banana trade, since bananas are the most widely traded fresh produce commodity globally, with leading exporters being Ecuador and Costa Rica and major importers, the United States and the European Union. Through various scenarios, we simulate congestion and time delays in the Panama Canal and report on the impacts of ongoing disruptions on shipment times, equilibrium shipment volumes, the supply and demand prices, quality levels at the supply markets and at the demand markets, and transportation costs. Our baseline numerical example results closely align with real-life data on export volumes of bananas, the associated supply and demand prices, and the transportation costs. The comprehensive numerical results reveal that reductions in transportation capacity and prolonged shipment times, as in the Panama Canal due to climate-related issues, lead to decreased banana shipment volumes, increased initial quality, but diminished final quality of bananas at demand markets. This exposes significant challenges for consumers, as well as for producers, as instances of transportation capacity disruptions and extended shipment times result in higher prices for lower-quality bananas.

Keywords Trade · Fresh produce · Networks · Quality deterioration · Variational inequalities · Bananas

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Published online: 04 June 2025

Springer

The numerical case study is on the banana trade.

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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

Email

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

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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.

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Chicago Tribune

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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

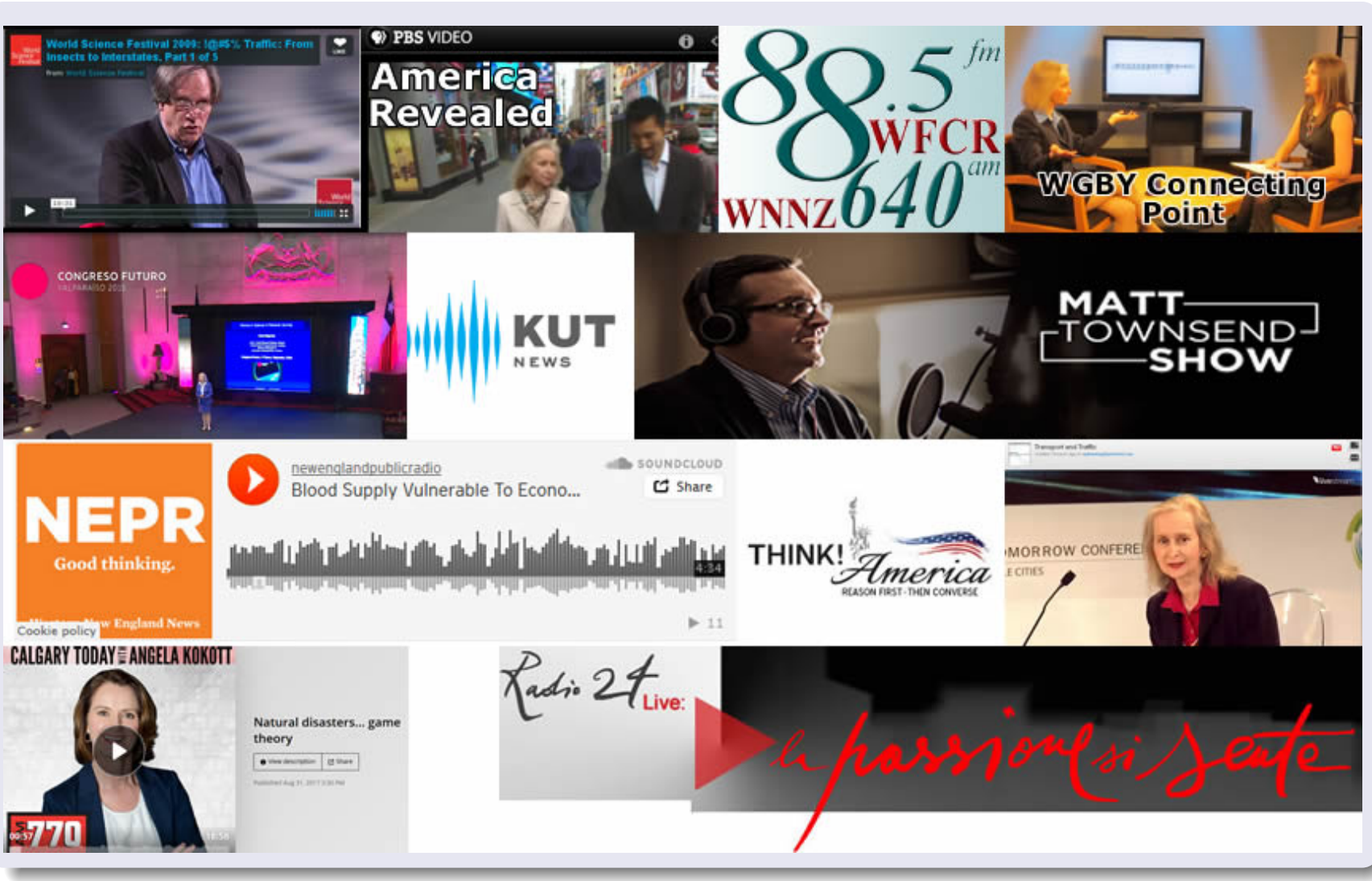
How disaster relief efforts could be improved with game theory

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



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 8.05am EDT

Email
Twitter 28
Facebook 1.1k
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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

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 altruistic donations, collection, testing, processing and distribution to hospitals and medical centers. The blood

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."

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

Operations Research for the Recovery and Reconstruction of Ukraine

By Anna Nagurney

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'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

Responding to Media Requests on Tariffs

I believe that it is important to respond to media requests on topics that your research can inform, such as that of our work on tariffs and trade.

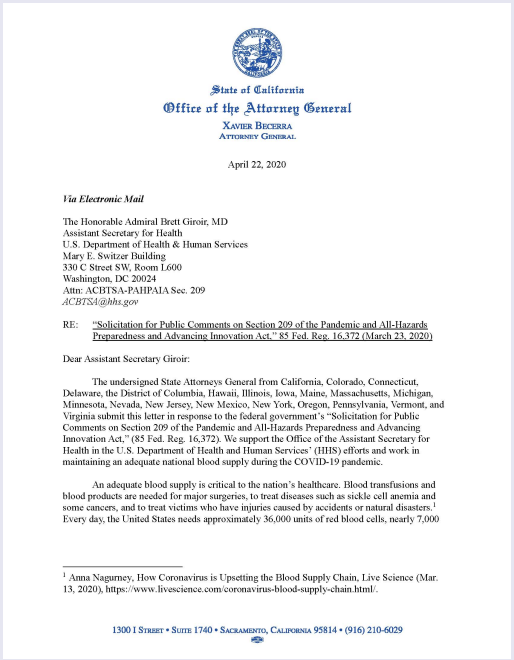
Computable mathematical models and associated analyses on tariffs and trade can provide valuable insights (including unexpected ones) for policy-makers and decision-makers.

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/.

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Hon. Brett Giroir
April 22, 2020
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Xavier Becerra, then CA Attorney General, became the Secretary of Health and Human Services in the US under President Biden!

Thank You Very Much!

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