Food Security and Multicommodity Agricultural International Trade: Quantifying Optimal Consumer Subsidies for Nutritional Needs

Professor Anna Nagurney

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

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The Paper

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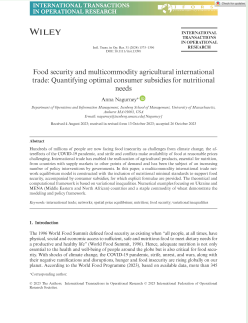

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Food security and multicommodity agricultural international trade: Quantifying optimal consumer subsidies for nutritional needs

Anna Nagurney*

Department of Operations and Information Management, Isenberg School of Management, University of Massachusetts, Amherst MA 01003, USA
E-mail: nagurney@isenberg.umass.edu [Nagurney]

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Abstract

Hundreds of millions of people are now facing food insecurity as challenges from climate change, the aftereffects of the COVID-19 pandemic, and strife and conflicts make availability of food at reasonable prices challenging. International trade has enabled the reallocation of agricultural products, essential for nutrition, from countries with supply markets to other points of demand and has been the subject of an increasing number of policy interventions by governments. In this paper, a multicommodity international trade network equilibrium model is constructed with the inclusion of nutritional minimal standards to support food security, accompanied by consumer subsidies, for which explicit formulae are provided. The theoretical and computational framework is based on variational inequalities. Numerical examples focusing on Ukraine and MENA (Middle Eastern and North African) countries and a staple commodity of wheat demonstrate the modeling and policy framework.

Keywords: international trade; networks; spatial price equilibrium; nutrition; food security; variational inequalities

1. Introduction

The 1996 World Food Summit defined food security as existing when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs for a productive and healthy life" (World Food Summit, 1996). Hence, adequate nutrition is not only essential to the health and well-being of people around the globe but is also critical for food security. With shocks of climate change, the COVID-19 pandemic, strife, unrest, and wars, along with their negative ramifications and disruptions, hunger and food insecurity are rising globally on our planet. According to the World Food Programme (2023), based on available data, more than 345

*Corresponding author.

The paper is a recipient of an Editor's Choice Award.

Outline of This Presentation

- **Background and Motivation**
- **The International Trade Model with Consumer Subsidies**
- **Equilibrium Conditions and Variational Inequality Formulation**
- **Consumer Subsidies**
- **Illustrative Examples**
- **Algorithmically Solved Numerical Examples and Sensitivity Analysis**
- **Summary and Conclusions**

Background and Motivation

Food Security

The 1996 World Food Summit defined food security as: “all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs for a productive and healthy life.”

The UN’s 2nd Sustainable Development Goal (SDG) aims for zero hunger and the achievement of food security and improved nutrition.

Food Insecurity

With shocks of climate change, the COVID-19 pandemic, strife, unrest, and wars, along with their negative ramifications and disruptions, hunger and food insecurity are rising globally on our planet.

Food Insecurity

According to the World Food Programme, more than 345 million people in 2023 were faced with high levels of food insecurity, a number more than twice the number in 2020.

The Food and Agricultural Organization (FAO) of the UN estimated that between 691 and 783 million people faced hunger in 2022.

The FAO reported that the prevalence of undernourishment (PoU) increased to about 9.9% in 2020, from 8.4% a year earlier, after being essentially unchanged from 2014 to 2019, and noted that the world is at a “critical juncture.”

International Trade

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

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

- **FAO reports that between 20 and 30 percent of the Ukrainian land previously used for cultivating winter crops will probably remain unsown due to the ongoing war**.

- **In addition, there have been immense challenges in getting the exports of agricultural products out of Ukraine with the blockade of the Black Sea in wartime and various bottlenecks**.

The International Trade Model with Consumer Subsidies

The International Trade Model with Consumer Subsidies

The international trade model with consumer subsidies for food security consists of n country supply markets and n country demand market and H commodities.

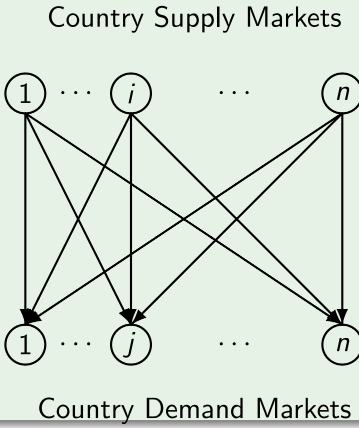


Table: Notation for the Model

Notation	Parameter Definition
t_j^l	the minimum amount required of nutrient l; $l = 1, \dots, L$, for the population in country demand market j; $j = 1, \dots, n$.
$\alpha^{l,h}$	the amount of nutrient l; $l = 1, \dots, L$, in a unit of commodity h; $h = 1, \dots, H$.
Notation	**Variable Definition**
s_i^h	the supply of commodity h; $h = 1, \dots, H$, at country supply market i; $i = 1, \dots, n$. We group all the commodity supplies into the vector $s \in R_+^{Hn}$.
d_j^h	the demand for commodity h; $h = 1, \dots, H$, at country demand market j; $j = 1, \dots, n$. We group all the commodity demands into the vector $d \in R_+^{Hn}$.
Q_{ij}^h	the shipment of commodity h; $h = 1, \dots, H$, from country supply market i; $i = 1, \dots, n$, to country demand market j; $j = 1, \dots, n$. We group all the commodity shipments into the vector $Q \in R_+^{H2n}$.
λ_j^l	the Lagrange multiplier (shadow price) associated with the minimum requirement of nutrient l in country demand market j, with $l = 1, \dots, L$ and $j = 1, \dots, n$. We group all such Lagrange multipliers into the vector $\lambda \in R_+^{Ln}$.
Notation	**Function Definition**
$\pi_i^h(s)$	the supply price function for commodity h; $h = 1, \dots, H$, at country supply market i; $i = 1, \dots, n$. We group all the commodity supply price functions into the vector $\pi(s) \in R^{Hn}$.
$\rho_j^h(d)$	the demand price function for commodity h; $h = 1, \dots, H$, at country demand market j; $j = 1, \dots, n$. We group all the commodity demand price functions into the vector $\rho(d) \in R^{Hn}$.
$c_{ij}^h(Q)$	the unit transportation cost associated with shipping commodity h; $h = 1, \dots, H$, from country supply market i; $i = 1, \dots, n$, to country demand market j; $i = 1, \dots, n$. We group the commodity unit transportation costs for all supply/demand market pairs into the vector $c(Q) \in R^{H2n}$.

The Conservation of Flow Equations

The supply, demand, and nonnegativity constraints are now presented. The conservation of flow equations are:

$$s_i^h = \sum_{j=1}^{n} Q_{ij}^h, \quad h = 1, \ldots, H; i = 1, \ldots, n; \tag{1}$$

$$d_j^h = \sum_{i=1}^{n} Q_{ij}^h, \quad h = 1, \ldots, H; j = 1, \ldots, n; \tag{2}$$

$$Q_{ij}^h \geq 0, \quad h = 1, \ldots, H; i = 1, \ldots, n; j = 1, \ldots, n. \tag{3}$$

The Food Security Nutritional Constraints

The food security nutritional constraints guarantee that the nutritional needs are met for each country's population and are:

$$\sum_{h=1}^{H} \alpha^{l,h} d_j^h \geq t_j^l, \quad l = 1, \ldots, L; j = 1, \ldots, n. \tag{4a}$$

In view of (2), we may rewrite the constraints in (4a) as:

$$\sum_{h=1}^{H} \alpha^{l,h} \sum_{i=1}^{n} Q_{ij}^h \geq t_j^l, \quad l = 1, \ldots, L; j = 1, \ldots, n. \tag{4b}$$

According to (4a) (and also (4b)), the minimum amount needed for nutrition from each nutrient (including calories) derived from all the commodities for the population in each country must be met. We refer to the t_j^ls as the minimum standards for nutrient l in country demand market j.

Lagrange Multipliers and Redefinition of Functions

In the statement of the international trade equilibrium conditions, we associate a Lagrange multiplier λ_j^l with the constraint in (4b) corresponding to nutrient l and country demand market j.

New multicommodity supply price functions $\tilde{\pi}_i^h(Q)$ for $h = 1, \ldots, H$; $i = 1, \ldots, n$, and new demand price functions $\tilde{\rho}_j^h(Q)$ for $h = 1, \ldots, H$; $j = 1, \ldots, n$, that are functions of the commodity shipments are now defined. This is doable because of conservation of flow equations (1) and (2).

$$\tilde{\pi}_i^h = \tilde{\pi}_i^h(Q) \equiv \pi_i^h(s), \quad h = 1, \ldots, H; i = 1, \ldots, n, \tag{5}$$

and

$$\tilde{\rho}_j^h = \tilde{\rho}_j^h(Q) \equiv \rho_j^h(d), \quad h = 1, \ldots, H; j = 1, \ldots, n. \tag{6}$$

The feasible set $\mathcal{K}^1 \equiv \{(Q, \lambda) | (Q, \lambda) \in R_+^{H2n+Ln}\}$.

The Equilibrium Conditions and Variational Inequality Formulation

• The equilibrium conditions expand the classical spatial price equilibrium conditions of Samuelson (1952) and Takayama and Judge (1971) to include food security in the form of minimum nutritional standards.

• We can handle nonseparable functions as well as nonlinear and asymmetric ones.

The International Trade Equilibrium Conditions

• The spatial price equilibrium framework, in a variational inequality context (cf. Florian and Los (1982), Dafermos and Nagurney (1984)), has yielded rich modeling advances and applications, especially to agricultural products (see, e.g., Nagurney and Aronson (1989), Nagurney, Dong, and Nagurney (2014), Nagurney (2021), Nagurney, Salarpour, and Dong (2022), Nagurney and Besik (2022), Nagurney et al. (2023)).

• In the absence of the minimum nutritional standards that must be met, the model collapses to a multicommodity spatial price equilibrium model.

Some Related Publications

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

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

A. Nagurney, D. Hassani, O. Nivievskyi, and P. Martyshev, "Multicommodity International Agricultural Trade Network Equilibrium: Competition for Limited Production and Transportation Capacity under Disaster Scenarios with Implications for Food Security," *European Journal of Operational Research* **314(1) (2024), pp 1127-1142.**

O. Nivievskyi and A. Nagurney, "Ukraine – Addressing the domestic humanitarian crisis and the effects of the war on global food systems," in *Food and Humanitarian Crises: Science and Policies for Prevention and Mitigation Proceedings of the Working Group*, **J. von Braun et al., Editors, Scripta Varia 154, LEV, Vatican City, 2024.**

The International Trade Equilibrium Conditions

Definition 1: The International Trade Equilibrium Conditions

A multicommodity shipment and Lagrange multiplier pattern $(Q^*, \lambda^*) \in \mathcal{K}^1$ is an international trade equilibrium with food security nutritional minimum standards if it satisfies the following conditions: for each commodity h; $h = 1, \ldots, H$, and for each pair of country supply and demand markets (i, j); $i = 1, \ldots, n$; $j = 1, \ldots, n$:

$$\tilde{\pi}_i^h(Q^*) + c_{ij}^h(Q^*) - \sum_{l=1}^{L} \alpha^{l,h} \lambda_j^{l*} \begin{cases} = \tilde{\rho}_j^h(Q^*), & \text{if } Q_{ij}^{h*} > 0, \\ \geq \tilde{\rho}_j^h(Q^*), & \text{if } Q_{ij}^{h*} = 0, \end{cases} \qquad (7)$$

and for each nutrient l; $l = 1, \ldots, L$, and for each country demand market j; $j = 1, \ldots, n$:

$$\sum_{h=1}^{H} \alpha^{l,h} \sum_{i=1}^{n} Q_{ij}^{h*} - t_j^l \begin{cases} = 0, & \text{if } \lambda_j^{l*} > 0, \\ \geq 0, & \text{if } \lambda_j^{l*} = 0. \end{cases} \qquad (8)$$

Variational Inequality Formulation

Theorem 1: Variational Inequality Formulation of the International Trade Equilibrium Conditions with Food Security Minimum Nutritional Standards

A multicommodity shipment and Lagrange multiplier pattern $(Q^*, \lambda^*) \in \mathcal{K}^1$ *is an international trade equilibrium with food security minimum nutritional standards according to Definition 1 if and only if it satisfies the variational inequality problem:*

$$\sum_{h=1}^{H}\sum_{i=1}^{n}\sum_{j=1}^{n}(\tilde{\pi}_i^h(Q^*) + c_{ij}^h(Q^*) - \sum_{l=1}^{L}\alpha^{l,h}\lambda_j^{l*} - \tilde{\rho}_j^h(Q^*)) \times (Q_{ij}^h - Q_{ij}^{h*})$$

$$+\sum_{l=1}^{L}\sum_{j=1}^{n}(\sum_{h=1}^{H}\alpha^{l,h}\sum_{i=1}^{n}Q_{ij}^{h*} - t_j^l) \times (\lambda_j^l - \lambda_j^{l*}) \geq 0, \quad \forall (Q, \lambda) \in \mathcal{K}^1. \tag{9}$$

Consumer Subsidies

Consumer Subsidies

Observe that equilibrium conditions (7) may be rewritten as: for each commodity h; $h = 1, \ldots, H$, and for each pair of country supply and demand markets (i, j); $i = 1, \ldots, n$; $j = 1, \ldots, n$:

$$\tilde{\pi}_i^h(Q^*)+c_{ij}^h(Q^*) \begin{cases} = \tilde{\rho}_j^h(Q^*) + \sum_{l=1}^L \alpha^{l,h}\lambda_j^{l*}, & \text{if } Q_{ij}^{h*} > 0, \\ \geq \tilde{\rho}_j^h(Q^*) + \sum_{l=1}^L \alpha^{l,h}\lambda_j^{l*}, & \text{if } Q_{ij}^{h*} = 0. \end{cases} \quad (10)$$

The expression $\sum_{l=1}^L \alpha^{l,h}\lambda_j^{l*}$ for each h and j provides the additional "value" associated with h and j and, in effect, is the additional price of the commodity that will guarantee that the commodity shipments will be such that the minimum nutritional standards are met in the country for nutrients needed by its population. **This is the subsidy.**

Consumer Subsidies

Also, this consumer subsidy is for a "unit" of the commodity and, in the case of agricultural commodities in international trade, the unit of measure is, typically, a ton.

The total financial outlay for the government of country j, for commodity h is :

$$\sum_{l=1}^{L} \alpha^{l,h} \lambda_j^* \sum_{i=1}^{n} Q_{ij}^{h*},$$

with the financial outlay covering subsidies for all commodities:

$$\sum_{h=1}^{H} \sum_{l=1}^{L} \alpha^{l,h} \lambda_j^* \sum_{i=1}^{n} Q_{ij}^{h*}.$$

Illustrative Examples

First, an example is presented without nutritional minimum standards and then the results given for the same example, but with an added nutritional minimum standard. The commodity is wheat, which is essential since it is used in flour for the production of bread, a staple in MENA countries, among other countries. Wheat, in addition to providing calories, is also a source of protein.

The country supply market is Ukraine, often called the bread basket of Europe. The period of time is 1 year and prior to the full-scale invasion of Ukraine by Russia on February 24, 2022. The country demand market is Lebanon. Without loss of generality, the country supply market of Ukraine is labeled by 1 and the country demand market of Lebanon by 1.

The unit of commodity shipment is a ton, which is quite standard for agricultural products in the context of international trade. Also, the economic functions are in a common currency - the US dollar.

Illustrative Examples

The supply price function in Ukraine is:

$$\pi_1(s) = .0001s_1 + 200.$$

The demand price function in Lebanon is:

$$\rho_1(d) = -.0001d_1 + 411,$$

and the unit transportation cost associated with shipping the wheat from Ukraine to Lebanon, which would be via rail and then the Black Sea, is:

$$c_{11} = .00002Q_{11} + 90.$$

Note that, in this example, one has that

$$s_1^* = d_1^* = Q_{11}^*.$$

Illustrative Examples

Solving for Q^*_{11} in the equilibrium condition, since $Q^*_{11} > 0$:

$$\pi_1 + c_{11} = \rho_1,$$

one obtains, after making use of the conservation of flow equations:

$$.0001Q_{11} + 200 + .00002Q_{11} + 90 = -.0001Q_{11} + 411,$$

which simplifies to:

$$.00022Q^*_{11} = 121,$$

or

$$Q^*_{11} = 550,000.$$

Furthermore, $\pi_1 = 255$, $c_{11} = 101$, and $\rho_1 = 356$, which are very reasonable.

This example is now expanded to include a nutritional minimum standard. Wheat (which is processed into flour) has 3,300,000 calories per ton. Plus, assuming 3,000 calories per day per individual (which is generous), and a population in Lebanon of 5.5 million, since there are 365 days in a year, $t_1 = 6.02 \times 10^{12}$.

Assuming that $\lambda_1^* > 0$, according to equilibrium condition (8), we obtain

$$3.3 \times 10^6 Q_{11}^* = 6.02 \times 10^{12},$$

and, therefore, $Q_{11}^* = 1.825 \times 10^6$.
The supply price is:

$$\pi_1 = 382.50,$$

the unit transportation cost is:

$$c_{11} = 126.50,$$

and the demand price is:

$$\rho_1 = 228.50.$$

Making use of the equality in equilibrium conditions (7) yield:

$$\lambda_1^* = 8.5 \times 10^{-5},$$

with

$$\alpha^1 \lambda_1^* = 280.50.$$

Hence, the consumer subsidy that the government of Lebanon should pay out is 280.50 **per ton of wheat.**

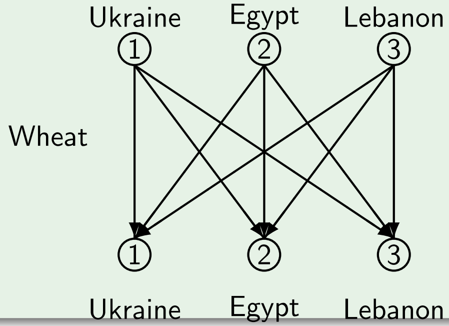
Without the subsidy, the total calories obtained by the Lebanese from wheat would be 18.15×10^{11}**, which is an order of magnitude less than** 6.02×10^{12}**, the amount obtained with the consumer subsidy.**

The total financial payout in terms of consumer subsidies (for all the tons) is, therefore,
$\alpha^1 \lambda_a^* Q_{11}^* = 280.50 \times 1.825 \times 10^6 = 511.91 \times 10^6$.

Algorithmically Solved Numerical Examples and Sensitivity Analysis

Numerical Examples

The numerical examples consist of three countries: Ukraine, Egypt, and Lebanon. The examples consist of Examples 1 through 3 and consider the commodity of wheat.



The modified projection method was implemented in Fortran and a Linux sytem at the University of Massachusetts used for the computations. The algorithm was initialized with all variables set to 0.00. The ζ was set to .01. The algorithm was deemed to have converged if the absolute value of all successive variable iterates

Example 1: Baseline

Example 1 is situated prior to Russia's invasion of Ukraine on February 24, 2022. There are no minimum nutritional standards for wheat. The nutrient considered is that of calories. Wheat is denoted by the superscript 1.

The country supply price functions for wheat are:

$$\pi^1_1(s) = .000002s^1_1 + 230,\ \pi^1_2(s) = .000002s^1_2 + 265,\ \pi^1_3(s) = .000155s^1_3 + 275.$$

The commodity unit transportation cost functions for wheat are:

$$c^1_{11}(Q) = .000001Q^1_{11} + 35,\ c^1_{12}(Q) = .000005Q^1_{12} + 80,\ c^1_{13}(Q) = .000025Q^1_{13} + 80$$

$$c^1_{21}(Q) = .001565Q^1_{21} + 80,\ c^1_{22}(Q) = .000001Q^1_{22} + 40,\ c^1_{23}(Q) = .001175Q^1_{23} + 50$$

$$c^1_{31}(Q) = .001375Q^1_{31} + 80,\ c^1_{32}(Q) = .001195Q^1_{32} + 50,\ c^1_{33}(Q) = .000095Q^1_{33} + 30$$

The country demand price functions for wheat are:

$$\rho^1_1(d) = -.000001d^1_1 + 320,\ \rho^1_2(d) = -.000001d^1_2 + 355,$$

$$\rho^1_3(d) = -.000017d^1_3 + 355.$$

Based on the equilibrium volumes in Example 1, the caloric needs of the populations in Egypt and Lebanon are not satisfied but they are in Ukraine.

Therefore, the impacts of imposing minimum nutritional caloric amounts in each of the three countries, based on the population of each country, are now explored in the next two examples.

Example 2

Example 2 has the identical data to that in Example 1 except that now minimum caloric requirements for the populations in Ukraine, Egypt, and Lebanon are included.

A population of 43 million is assumed for Ukraine, a population of 109 million for Egypt, and a population of 5.5 million for Lebanon.

A caloric minimum of 3,000 per individual is assumed and 365 days to the year. Wheat has 3,300,000 calories per ton. Since a single nutrient (calories) is considered and wheat can have a substantial amount of protein, the l in the notation is suppressed.

Hence, $\alpha^1 = 3,300,000$, and $t_1 = 4.71 \times 10^{13}$, $t_2 = 1.19 \times 10^{14}$, and $t_3 = 6.02 \times 10^{12}$.

Example 3

Example 3 has the identical data to that in Example 2 except that now each individual in each country has a minimum caloric requirement of only 2,000 calories.

α^1 remains at $3,300,000$, but now $t_1 = 3.14 \times 10^{13}$, $t_2 = 7.96 \times 10^{13}$, and $t_3 = 4.02 \times 10^{12}$.

Table: Equilibrium Solution for Examples 1, 2, and 3

Equilibrium Wheat Commodity Flows	Ex. 1	Ex. 2	Ex. 3
Q_{11}^{1*}	11650770.00	14200000.00	9520001.00
Q_{12}^{1*}	1335727.75	8664518.00	5833827.00
Q_{13}^{1*}	362736.38	1444176.25	961641.25
Q_{21}^{1*}	0.00	0.00	0.00
Q_{22}^{1*}	10912198.00	27382862.00	18261452.00
Q_{23}^{1*}	7732.52	21733.81	13132.48
Q_{31}^{1*}	0.00	0.00	0.00
Q_{32}^{1*}	0.00	12619.76	4720.99
Q_{33}^{1*}	163465.44	354090.00	245226.22
Wheat Supply Prices at Equilibrium	**Ex. 1**	**Ex. 2**	**Ex. 3**
$\pi_1^1(s^*)$	256.70	278.62	262.63
$\pi_2^1(s^*)$	286.84	319.81	301.55
$\pi_3^1(s^*)$	300.34	331.84	313.55
Transportation Costs at Equilibrium	**Ex. 1**	**Ex. 2**	**Ex. 3**
$c_{11}^1(Q^*)$	46.65	49.20	44.52
$c_{12}^1(Q^*)$	86.68	123.32	109.17
$c_{13}^1(Q^*)$	89.07	116.10	104.04
$c_{21}^1(Q^*)$	80.00	80.00	80.00
$c_{22}^1(Q^*)$	50.91	67.38	58.26
$c_{23}^1(Q^*)$	59.09	75.54	65.43
$c_{31}^1(Q^*)$	80.00	80.00	80.00
$c_{32}^1(Q^*)$	50.00	65.08	55.64
$c_{33}^1(Q^*)$	45.53	63.64	53.30
Wheat Demand Prices at Equilibrium	**Ex. 1**	**Ex. 2**	**Ex. 3**
$\rho_1^1(d^*)$	308.35	305.80	310.48
$\rho_2^1(d^*)$	342.75	318.94	330.90
$\rho_3^1(d^*)$	345.92	324.06	334.26

Consumer Subsidies

For Example 2, the subsidy in Ukraine is: 19.02. The subsidy in Egypt is: 78.00, and the subsidy in Lebanon is: 71.26.

For Example 3: the consumer subsidy is 0.00 in Ukraine. The consumer subsidy is 38.40 in Egypt, and the consumer subsidy is 32.79 in Lebanon. Ukraine is able to meet its nutritional caloric requirements by itself and no imports are needed, which is quite reasonable. Note that the subsidies for consumers in all three countries are lower than in Example 2 and that is because the caloric minimum is set at 2,000 rather than at 3,000.

Wheat farmers get the highest price per ton of wheat in Example 2 and the lowest in Example 1. This shows that, through the subsidization of consumers, producers can also benefit. The highest commodity shipments are obtained in Example 2 across all the country trade flows. The prices are reasonable - recall that they are for a ton of grain (see, also, Nagurney et al. (2023)).

Sensitivity Analysis

Sensitivity analysis is now conducted using Example 3.

Specifically, with the major invasion of Ukraine by Russia on February 24, 2022, farmers in Ukraine have been faced with many challenges and the challenges are affecting the supply prices of Ukrainian wheat (cf. Nagurney et al. (2023)).

Recall that the intercept in Ukraine's supply price function in Examples 1 through 3 is 230. This term is increased, which would reflect disruptions to farming.

The consumer subsidies are displayed that Ukraine, Egypt, and Lebanon would need to pay to guarantee that the caloric needs of their respective population are met.

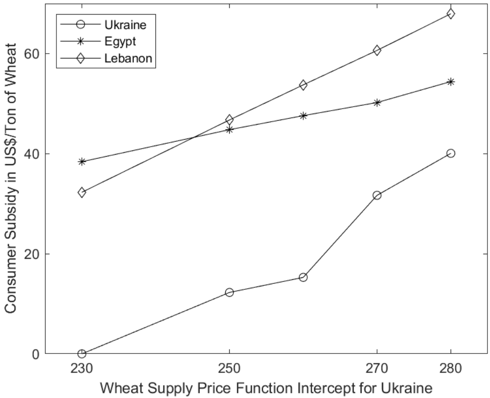


Figure: Sensitivity Analysis for the Supply Price Function Intercept for Ukraine in Example 3

Summary and Conclusions

Summary and Conclusions

• **Food insecurity and hunger have been growing globally** with climate change, the COVID-19 pandemic, as well as major conflicts including Russia's war on Ukraine exacerbating the pain and suffering.

• **International trade has served as a mechanism for the allocation of resources and products including agricultural ones.**

• **Nutritious food is essential** to a thriving, healthy citizenry and, thus, governments have, historically, made use of various policies for agricultural trade from the imposition of tariffs and quotas to subsidies for farmers.

• In this paper, we construct **an integrated framework for multicommodity international trade with a focus on food security through minimum nutritional standards that are enabled through consumer subsidies.**

Summary and Conclusions

• The **theoretical framework is that of variational inequalities**, which is utilized for the formulation of the governing equilibrium conditions (and alternative such formulations are provided), qualitative analysis, as well as for the construction of an algorithm that has nice features for implementation for our model.

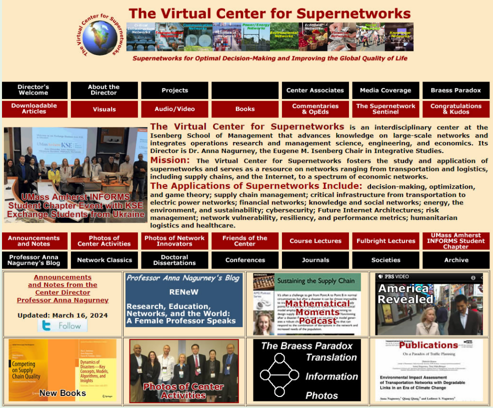
• In addition, we propose **explicit formulae for the consumer subsidies**.

• The model is illustrated via **examples drawn from the real world** - that of Russia's war on Ukraine and the impacts on food insecurity - along with sensitivity analysis.

• The results demonstrate that **a local disruption can have impacts on food security in multiple countries**.

• This work **adds to the literature on international trade and food security with an emphasis on nutrition and government interventions**.

Thank You Very Much!



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