Global Supply Chain Networks and Tariff Rate Quotas: Equilibrium Analysis with Application to Agricultural Products

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Background and Motivation

Nations engage in trade to increase their productivity levels, employment rates and general economic welfare.

Products as diverse as fresh produce and other food products, to steel and aluminum are transported across national boundaries through global supply chain networks.

With increased level of world trade, competition has become even more relentless.

Governments use trade policies to protect their less competitive domestic firms.

Background and Motivation

Trade policies: tariffs, quotas, **tariff rate quotas (TRQs)**.

TRQ is a two-tiered tariff, consisting of a lower in-quota tariff and a higher over-quota tariff.

43 World Trade Organization members have a total of 1,425 tariff rate quotas in their trade commitments.

The world's four most important food crops: rice, wheat, corn, and bananas have all been subject to tariff rate quotas.

Background and Motivation

Trade policy instruments are in the news almost everyday with the current economic and political climate.

The imposition of trade policy instruments by certain countries, leading to retaliation by other countries, resulting in trade war.



Contributions

- Global supply chain network model with the incorporation of tariff rate quotas (TRQs)
- Firms that seek to maximize their profits
- Provide a computable mathematical models for evaluating the impacts of trade policy tools
- Has been a challenging task to formulate tariff rate quotas (TRQs)
- A case study is provided on avocados with the United States, Mexico, and China

Literature Review

Perfect Competition:

- Tariff rate quotas (TRQs) have been deemed challenging to formulate; models have focused almost exclusively on **spatial price equilibrium**.

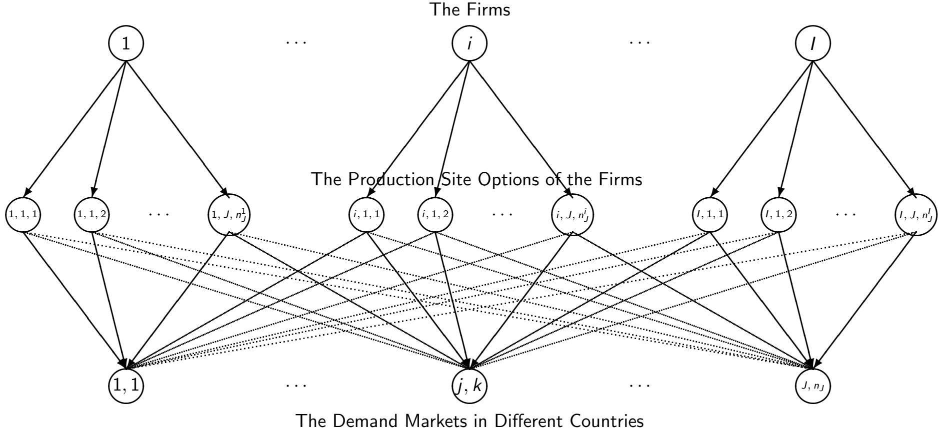
  Samuelson (1964), Takayama and Judge (1964, 1971), Nagurney (1999, 2006), Daniele (2004), Li, Nagurney, and Yu (2018), Nagurney, Besik, and Dong (2019).

Imperfect Competition:

- In many industrial sectors, the more appropriate framework is that of imperfect competition, as in the case of **oligopolistic competition**.

  Shono (2001), Maeda, Suzuki, and Kaiser (2001, 2005).

The Global Supply Chain Network Topology



Tariff Rate Quotas: Groups, Under-quota, Over-quota

We introduce the notation for groups denoted by G_g, consisting of production sites and the demand markets in the country that is imposing the tariff rate quota.

Associated with each group G_g, there is an under-quota tariff $\tau^u_{G_g}$.

Associated with each group G_g, there is an over-quota tariff $\tau^o_{G_g}$, where $\tau^u_{G_g} < \tau^o_{G_g}$.

Strategic Variables

Q_{ihl}**:** denotes the volume of the product manufactured/produced by firm i at production site $h \in \mathcal{J}_i$ and then shipped to demand market l for consumption.

Q_i**:** is the vector of nonnegative product flows, where $Q_i = \{Q_{ihl}; h \in \mathcal{J}_i, l \in \mathcal{K}\}$.

λ_{G_g}: denotes the quota rent equivalent for all G_g.

Cost Functions and Conservation of Flow

Production Cost Functions

Each firm i; $i = 1, \ldots, I$, is faced with a production cost function f_{ih} associated with manufacturing the product at h where we have that:

$$f_{ih} = f_{ih}(Q), \quad \forall h \in \mathcal{J}_i. \tag{1}$$

Transportation Cost Functions

Each firm i; $i = 1, \ldots, I$, encumbers a transportation cost c_{ihl} associated with transporting the product from production site node h to demand market node l, where

$$c_{ihl} = c_{ihl}(Q), \quad \forall h \in \mathcal{J}_i, \forall l \in \mathcal{K}. \tag{2}$$

Conservation of Flow

The demand at each demand node l; $\forall l \in \mathcal{K}$, is denoted by d_l and must satisfy the following conservation of flow equation:

$$\sum_{i=1}^{I} \sum_{h \in \mathcal{J}_i} Q_{ihl} = d_l. \tag{3}$$

Demand Price Functions

Demand Price Functions

The consumers, located at the demand markets, reflect their willingness to pay for the product through the demand price functions ρ_l, $\forall l \in \mathcal{K}$, with these functions being expressed as:

$$\rho_l = \rho_l(d). \tag{4a}$$

In view of (3), we can redefine the demand price functions (4a) as follows:

$$\hat{\rho}_l = \hat{\rho}_l(Q) \equiv \rho_l(d), \quad \forall l \in \mathcal{K}. \tag{4b}$$

Utility Functions of Firms

Utility/profits of the firms that are subject to TRQs:

$$U_i^G = \sum_{h\in\mathcal{J}_i}\sum_{l\in\mathcal{K}}\hat{\rho}_l(Q)Q_{ihl} - \sum_{h\in\mathcal{J}_i} f_{ih}(Q) - \sum_{h\in\mathcal{J}_i}\sum_{l\in\mathcal{K}} c_{ihl}(Q) - \sum_{G_g\in\mathcal{I}^i}(\tau^u_{G_g}+\lambda^*_{G_g})\sum_{(h,l)\in G_g} Q_{ihl}. \quad (5a)$$

Utility/profits of the firms that are *not* subject to TRQs:

$$U_i = \sum_{h\in\mathcal{J}_i}\sum_{l\in\mathcal{K}}\hat{\rho}_l(Q)Q_{ihl} - \sum_{h\in\mathcal{J}_i} f_{ih}(Q) - \sum_{h\in\mathcal{J}_i}\sum_{l\in\mathcal{K}} c_{ihl}(Q). \quad (5b)$$

The Global Supply Chain Network Model with TRQs

Definition 1: Global Supply Chain Network Equilibrium Under TRQs

A product flow pattern Q^* and quota rent equivalent λ^* is a global supply chain network equilibrium under tariff rate quotas if, for each firm i; $i = 1, \ldots, I$, the following conditions hold:

$$\hat{U}_i(Q_i^*, Q_{-i}^*, \lambda^*) \geq \hat{U}_i(Q_i, Q_{-i}^*, \lambda^*), \quad \forall Q_i \in K_i, \tag{6}$$

where $Q_{-i}^* \equiv (Q_1^*, \ldots, Q_{i-1}^*, Q_{i+1}^*, \ldots, Q_I^*)$, and
$K_i \equiv \{Q_i | Q_i \in R_+^{\sum_{j=1}^J Kn_j^i}\}$
and for all groups G_g:

$$\lambda_{G_g}^* \begin{cases} = \tau_{G_g}^o - \tau_{G_g}^u, & \text{if} \quad \sum_{i=1}^I \sum_{(h,l)\in G_g} Q_{ihl}^* > \bar{Q}_{G_g}, \\ \leq \tau_{G_g}^o - \tau_{G_g}^u, & \text{if} \quad \sum_{i=1}^I \sum_{(h,l)\in G_g} Q_{ihl}^* = \bar{Q}_{G_g}, \\ = 0, & \text{if} \quad \sum_{i=1}^I \sum_{(h,l)\in G_g} Q_{ihl}^* < \bar{Q}_{G_g}. \end{cases} \tag{7}$$

Variational Inequality Formulations

Theorem 1: Variational Inequality Formulation of the Global Supply Chain Network Equilibrium Under TRQs

A product flow and quota rent equivalent pattern $(Q^*, \lambda^*) \in \mathcal{H}$ is a global supply chain network equilibrium under tariff rate quotas according to Definition 1 if and only if it satisfies the variational inequality:

$$-\sum_{i=1}^{I} \sum_{h \in \mathcal{J}_i} \sum_{l \in \mathcal{K}} \frac{\partial \hat{U}_i(Q^*, \lambda^*)}{\partial Q_{ihl}} \times (Q_{ihl} - Q^*_{ihl})$$

$$+\sum_{g} \left[\bar{Q}_{G_g} - \sum_{i=1}^{I} \sum_{(h,l) \in G_g} Q^*_{ihl} \right] \times \left[\lambda_{G_g} - \lambda^*_{G_g} \right] \geq 0, \quad \forall (Q, \lambda) \in \mathcal{H}. \quad (8)$$

Variational Inequality Formulations

Corollary 1: Variational Inequality Formulation for the Global Supply Chain Network Without TRQs

In the absence of tariff rate quotas, the equilibrium of the resulting global supply chain network model collapses to the solution of the variational inequality: determine $Q^* \in \bar{K}$, satisfying:

$$-\sum_{i=1}^{I} \sum_{h \in \mathcal{J}_i} \sum_{l \in \mathcal{K}} \frac{\partial U_i(Q^*)}{\partial Q_{ihl}} \times (Q_{ihl} - Q^*_{ihl}) \geq 0, \quad \forall Q \in \bar{K}. \tag{9}$$

Case Study on Avocados

Representation of avocado trade between Mexico, US, and China.

Mexico produces more avocados than any other country in the world, about a third of the global total.

Mexico exported more than 1.7 billion pounds of Haas avocados to the US.

With about 90% of the avocados imported from Mexico to the United States coming from the state of Michoacan in Mexico.

Jalisco, the second-largest avocado-producing state in Mexico, accounts for about 6 percent of total Mexican production.

Case Study on Avocados

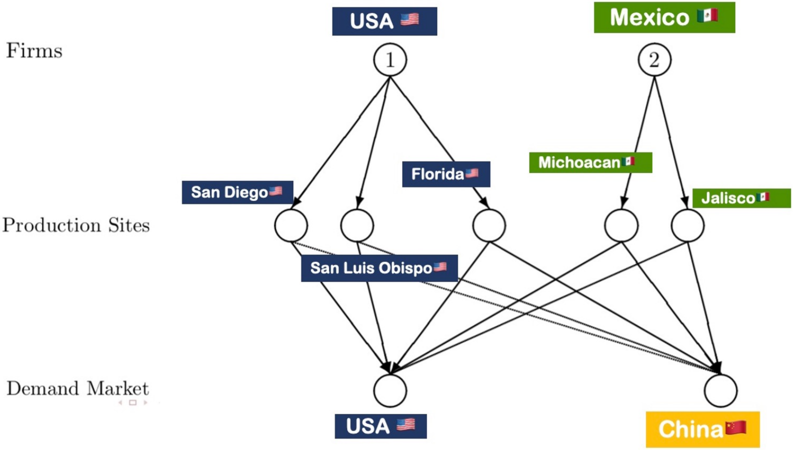
The volume of avocado imports into the United States has surpassed even the volume of bananas.

US domestic avocado consumption has risen to approximately 6.5 pounds per person annually, as compared to only 1.4 in 1990.

The United States is among the world's top ten avocado producers.

Mexico is also one of the largest suppliers of avocados to China.

Combined Network Topology of Numerical Examples



Case Study Insights

The United States imposes TRQs for the avocados exported from Mexico.

- The demand price of avocados in the United States increases.
- US government collects a great deal of rent coming from tariff rate quotas.

US based food firm opens a new production site in the United States.

- Lowers the demand price of avocados in the US.

New demand market in China emerges with retaliatory TRQs to US.

- Profit of the firm in the US drops over 50%.
- Profit of the firm in Mexico increases.
- Chinese government collects tariff quota rent.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Summary and Conclusions

- We constructed a modeling and computational framework for competitive global supply chain networks in the presence of trade policies in the form of tariff rate quotas.
- To-date, there has been limited modeling work integrating oligopolistic firms and TRQs.
- The numerical examples that comprise the case study quantify impacts of tariff rate quotas on consumer prices, on product flows, as well as on the firms' profits.
- The results demonstrate that TRQs can be effective in reducing product flows from countries on which they are imposed but at the expense of the consumers prices.

June 19th, 2019

Higher grocery bills

A farmer harvesting avocados in the Mexican state of Michoacan. If tariffs materialize, American consumers are likely to feel them first in the price of fresh fruits and vegetables. Ronaldo Schemidt/Agence France-Presse — Getty Images

The United States imported nearly $28 billion in food and drink from Mexico last year, including more than two-fifths of its total imports of fruits and vegetables. Tariffs on those goods are likely to show up in higher prices in produce sections and grocery shelves within weeks.

Questions and Comments

THANK YOU!

For more information: https://supernet.isenberg.umass.edu/