OPTIMAL TARIFFS FOR TRADE IN DIFFERENTIATED PRODUCTS:  
THE NORTH AMERICAN ONION TRADE

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As world markets for fresh vegetables have expanded, the use of trade policies to increase the competitiveness of exports or to protect domestic vegetable industries against imports has become more prevalent. Impediments to imports of fresh vegetables include both seasonal import tariffs assessed at higher rates during domestic production periods and nontariff barriers, such as phytosanitary (plant health) regulations.

Government policies designed to increase the ability of domestic producers to compete in export markets include production and export subsidies. Governments may also extract revenues from the export of fresh vegetables by imposing production or export taxes or by controlling production and exports through government sanctioned marketing boards (Buckley).

The study develops a model of North American onion trade among Canada, Mexico, and the United States as a nonzero-sum, finite, noncooperative game. Each country is assumed to maximize its social welfare by setting an optimal trade policy.

International Trade in Onion: The North American Market

World production and trade for onions have increased steadily in the last two decades in both developed and developing nations. Important international fresh onion traders in North America include the United States, Mexico, and Canada. The U.S. and Canada play significant roles as both exporters and importers of fresh onions.

Mexico is a leading exporter as onions are one of its major horticultural crops, ranking fourth in area harvested (10.9%) and in production (12.3%) (Agriculture in a North American Free Trade Agreement, USDA, 1992). Mexico is the leading exporter of fresh onions to the
United States. The value of fresh onions imported from Mexico was $90.35 million in 1993, representing 85 percent of total onion imports to the United States and about 10 percent of the value of fresh vegetable imports from Mexico. Canada is the second largest foreign exporter of fresh onions to the United States.

Recent work on international onion trade has examined the competitive conditions and the impact of NAFTA on trade flows. Fuller et al. (1991) examined competition from Mexican imports for the U.S. market for Texas onions. The study confirmed that relative prices, other economic variables, as well as exchange rates were important factors. Fuller, Gutierrez, and Capps estimated the import demands of Canada and Japan for U.S. onions. Relative prices, tariff rates, and other economic variables were found to be important. Further, import demand elasticities were found to be quite different for the two countries. Fuller, Gillis, and Ziari analyzed the impact of liberalizing trade in onions between the United States and Mexico. They predict a large percentage increase in U.S. imports of Mexican onions with reduced tariffs along with a decline in U.S prices.

**International Trade Models and Game Theory**

The importance of product differentiation in international trade has been examined in both theoretical and empirical research. Dixit highlighted product differentiation as a reason for the emergence of imperfect competition in international trade. He noted that product differentiation may exist due to physical characteristics when consumer tastes differ, brand images created by persuasive advertising, or transport costs across geographic regions. Rogoff’s analysis of the purchasing power parity doctrine confirmed that international goods markets remain segmented and that trading frictions persist due to transportation costs,
threatened or actual tariffs, nontariff barriers, and information costs. He noted that deviations from the law of one price are remarkably volatile across a wide range of goods, even among highly traded goods such as agricultural commodities.

Armington developed a model which assumes that commodities may be imperfect substitutes when consumers of a commodity in a particular country distinguish a commodity according to its origins. The Armington model assumes that import demands are weakly separable and homothetic among import sources. Within a market, trade patterns change only with relative price changes, and the elasticities of substitution between all pairs of products (such as U.S. and Mexican onions) are identical and constant.

Product differentiation by origin is a key aspect of international trade which is included in this study. Importers are assumed to treat onions imported from different countries as differentiated goods. The differences between onions from different origins makes the three types of onions dissimilar but highly competitive with each other.

Consumers distinguish differences in onions by place of production and variety so that onions produced in one country are imperfect substitutes for onions produced in another country. Consumers also have different demands for onions originating from domestic suppliers and different foreign suppliers. Due to imperfect substitution between onions from different sources, international trade for onions is assumed to be imperfectly competitive.

An important contribution of this study concerns the treatment of foreign reactions to individual trade policies. A framework is developed to endogenize imperfectly competitive behavior in international agricultural markets. Helpman and Krugman emphasized the role of quantification in theoretical international trade models to measure the impact of imperfect
competition and the gains from optimal deviations from free trade policies.

Game theory emphasizes the study of rational decision making based on the assumption that agents attempt to maximize utility. Schotter and Schwodiauer proposed the application of game theory to the analysis of international trade with imperfect market structure and government intervention.

The theory of games provides a set of mathematical techniques for analyzing situations in which each agent's utility depends not only on that person's own actions but also on the actions of the others (McMillan). Each agent takes these interdependencies into account when deciding on an action. Many important policy issues in international trade involve the potential for game-theoretic behavior. Strategic interdependence exists since the best actions of one agent depend upon the actions of another agent, and vice versa.

The normal form expression for a game theory model will be utilized throughout the paper. Each player attempts to maximize a utility function where the outcome depends not only upon that individual's choice but upon the choices of each of the other players. In turn, the choices of the other players are influenced by the choice they think that a player is going to make. Each player $i$ chooses a strategy $x_i$ from the set $s_i$ of possible strategies. Each agent's utility $L^j$ depends on every players' strategy: $L^j = L^j(x_1, ..., x_N, i = 1, ..., N)$.

The nonzero-sum game used here to model the North American trade in fresh onions has elements of both conflict and cooperation. Each agent has incentives to bargain for an outcome where the sum of utilities is relatively high even though the interests of each agent are in conflict over shares in the sum. The non-cooperative game analyzed here recognizes that there are no institutions which act to ensure that promises of each agent are kept.
The dynamic elements allow each player to use a strategy that depends on previous actions and obtains additional, updated information throughout the decision process. The players act more than once and time plays a role.

For each country the payoff function is the social welfare function defined as a function of the imports and exports of the country and is implicitly a function of the tariff rates imposed by all three countries. Each country chooses a pure strategy of tariff rates without mutual cooperation, maximizing its social welfare function on the assumption that the strategies of the other countries remain unaltered.

The general objective of this study is to model the North American onion trade as a nonzero-sum, finite, noncooperative game, analyzing the reaction of one country to the changes of trade policies of other countries. This study includes Canada, Mexico, and the United States. Each country is assumed to maximize its social welfare by setting its optimal trade policy in the form of tariffs. As product differentiation is a basic assumption for this study, consumers distinguish onions by country of origin.

The paper proceeds in the following manner. Estimated supply and demand functions for the three countries are presented. From these equations, the nonzero-sum, finite, noncooperative game is developed for the North American onion trade. Then, the Nash equilibrium results of the game and the impacts of NAFTA on the North American onion trade are presented. Summary and conclusions follow.
**Specification and Estimation of the Econometric Model**

The specified demand and supply functions are consistent with the theories of international trade, product differentiation by origin, and an imperfectly competitive market structure for the international trade of onions. Each country's total demand for onions includes the demand for domestic onions and import demand for onions from other countries. Each country's total supply of onions includes both domestic and import supplies of onions. Annual data from 1968 to 1992 were used to estimate the econometric model.

A rational expectations model is used to generate price expectations in the supply equations. The model is estimated following the two-step, two-stage least squares method of Cumby, Huizinga, and Obstfeld (1983). The resulting estimates are asymptotically efficient in the class of instrumental variable estimators when the residuals from the equations are autocorrelated and when instruments are predetermined, but not strictly exogenous. Two-stage least squares was used to estimate the demand equations by country.

Durbin-Watson tests and Durbin's h-test, which is valid for equations with lagged dependent variables as regressors, showed that the disturbances of most equations exhibit first-order autocorrelation. The Prais-Winston transformation was used to correct this effect and regain efficient estimates.

**The Noncooperative Game Theory Model**

With the estimated demand and supply functions, price linkage equations and the government trade policies, the North American fresh onion trade model can be converted to a nonzero-sum finite noncooperative game. Canada, Mexico, and the United States are the three players, individually choosing optimal trade policies from a finite strategy set to
maximize their own social welfare.

Each country is assumed to maximize a social welfare function defined over three
interest groups: consumers, producers, and the government as represented by taxpayers. Any
changes in trade policy will influence domestic and international onion prices, trade flows, as
well as the welfare of consumers, producers, and the government.

Consumer welfare of one country depends on the consumption of onions and is
measured by consumer surplus. Total consumer surplus (CS) for each country is the sum of
consumer surplus from the consumption of domestic onions and onions imported from other
countries. Producer welfare (PS) is measured by producer surplus and includes two
components: surplus from domestic supply and surplus from export supply. Government
revenue (GR) is the amount that the government receives from imposing an import tariff.

The objective function for one country can be expressed as

\[
\max L_i (t_1, t_2, t_3) = CS_i + PS_i + GR_i, \quad (1)
\]

subject to

\[
BY_i + \hat{\Gamma}X_i = 0, \quad (2)
\]

where i represents the three countries, \( t_i \) is the tariff imposed by \( i^{th} \) import country, \( L_i \) is the
utility function of the \( i^{th} \) import country.

Equation (2) is the system of export supply and import demand equations including the
tariff rates (\( t_1, t_2, \) and \( t_3 \)) of each country in matrix notation. \( B \) is the matrix of estimated
coefficients of the endogenous variables, and \( \hat{\Gamma} \) is the matrix of estimated coefficients of the
exogenous variables. \( Y_i \) and \( X_i \) denote the endogenous variables and the exogenous
variables, respectively.

The three countries in the game choose their pure strategies based on tariff rates without mutual cooperation. Each country adjusts its strategy to maximize its social welfare function on the assumption that the strategies of the other countries remain unchanged. The process of such noncooperative adjustments leads to the Nash noncooperative equilibrium at which no country can do better than play its Nash strategy given that all other countries are playing their Nash strategies.

Each country chooses the optimal tariff rate from its pure strategy set \( t_i \) to maximize social welfare. Based on historical data, the range of the strategy set or tariff rates for this study is: \( t_i = [-0.25, 0.25] \) with a step size of 0.01. An iterative numerical approach is used to obtain the Nash equilibrium solution. This procedure is summarized in the following steps:

Step I. Fix the initial tariff rates of Mexico \( (t_2^0) \) and the U.S. \( (t_3^0) \) to the range \(-0.25 \leq t_2^0, t_3^0 \leq 0.25\) and solve equation (2) to obtain the market equilibrium prices and quantities for each \( t_i \) from the strategy set of Canada. Calculate consumer surplus, producer surplus and government revenue for Canada using the equilibrium prices and quantities. Obtain the total social welfare of Canada \( L_1 \). Compare all the values of \( L_1 \) of each \( t_1 \) to find the optimal tariff rate \( t_1^* \) which maximizes the value of social welfare \( L_1^* \) of Canada.

Step II. Consider the optimal tariff rate of Canada \( (t_1^*) \) and the U.S. tariff rate \( t_3^0 \) as constant and follow the same procedure in Step I to find the optimal tariff of Mexico \( (t_2^*) \) which maximizes the value of its social welfare \( L_2^* \).

Step III. Given the optimal tariff rates of Canada \( (t_1^*) \) and Mexico \( (t_2^*) \), follow the same
procedure in Step I to obtain the U.S. optimal tariff rate \((t^*_1)\) which also maximizes the value of its social welfare \(L^*_1\).

Step IV. Take the optimal tariff rates of Mexico \((t^*_2)\) and the U.S. \((t^*_3)\) and repeat Step I to obtain a new optimal tariff rate for Canada.

The process is continued until no country finds it advantageous to change its optimal tariff rate. The result is a Nash equilibrium at which no country can increase its payoff by unilaterally deviating from its Nash strategy. To check the consistency and stability of the Nash equilibrium, alternative sets of initial tariff rates are assigned to \(t_i\) and a different country is selected to be the first country to start playing the game.

**Impacts of NAFTA on the North American Fresh Onion Trade**

The North American Free Trade Agreement (NAFTA) creates two separate bilateral agreements, one between the United States and Mexico, and the other, between Canada and Mexico. Under NAFTA, all parties agreed to remove the tariffs on fresh onion trade over a 10-year period (NAFTA Situation and Outlook Series, USDA, ERS, May 1995).

To analyze the impact of NAFTA on the North American fresh onion economy, both free trade and current tariff rates are incorporated into the structural form of the system of export supply and import demand equations to find the equilibrium prices, trade flows, and social welfare for each country. Results for the free trade, current tariff rates, and Nash tariff rates are presented in Table 1 for purposes of comparison.
Impacts on Canada

Eliminating tariffs will lower domestic producer prices for onions from $8.12/cwt to $7.27/cwt in Canada. The prices of both imported Mexican onions and U.S. onions will also decline from $23.99/cwt and $16.56/cwt to $21.85/cwt and $14.41/cwt, respectively. Under free trade the total onion consumption in Canada will slightly increase from 4,902.97 thousand cwt. to 4,907.18 thousand cwt.

Canadian consumers will consume more U.S. onions and total import demand for U.S. onions will increase from 1,746.66 thousand cwt. to 1,778.36 thousand cwt. Consumer surplus for Canada is projected to increase 1.7 percent from $6.12 million to $6.23 million. Due to lower prices and the reductions in domestic demand and exports, the total supply of Canadian onions and producer surplus will decrease 5.6 percent. The removal of tariffs will benefit Canadian consumers and result in a decline in producer surplus for Canadian onion producers. Lower prices for domestic producers and higher imports of U.S. onions may result in the exit of some Canadian onion farmers from the industry.

Impacts on Mexico

Onion prices for Mexican producers under NAFTA will increase from $8.40/cwt to $8.49/cwt, and the price of imported U.S. onions will decrease from $12.92/cwt to $11.54/cwt. The total supply of Mexican onions will modestly increase due to higher prices and the expansion of Mexican onion exports to the United States. The total supply of onions exported from the United States to Mexico is projected to increase from 233.23 thousand cwt. to 253.73 thousand cwt. The producer surplus of Mexico will slightly increase under NAFTA.
The consumption of domestic onions is projected to decline due to the higher price of Mexican onions. Imports of U.S. onions enter Mexico due to lower prices for U.S. onions. Total Mexican onion consumption will decrease from 12,988.63 thousand cwt. to 12,932.26 thousand cwt. The net effect of removal of tariffs in the North American fresh onion trade will be to increase the value of the social welfare function for Mexico. Free trade will benefit Mexican onion producers while yielding slightly negative impacts for Mexican consumers.

Impacts on the United States

The removal of tariffs will lower the U.S. domestic producer price from $12.08/cwt to $11.31/cwt. The prices of both imported Canadian and Mexican onions will also decline. The total supply of onions to the United States will decrease due to lower prices in the domestic and foreign markets. Onion exports from the United States are projected to increase by about 2.6 percent under NAFTA even as producer surplus declines by 4.5 percent.

Though onion prices in the United States are projected to decline under NAFTA, total U.S. onion consumption will modestly decrease due to reduced supplies of domestic onions and imports from Canada. The import demand for Mexican onions will increase from 3,347.64 thousand cwt. to 3,445.59 thousand cwt. under NAFTA. Both U.S. consumers and producers will be adversely affected by the removal of tariffs in North American onion trade as the value of the U.S. social welfare function is projected to decline by 2 percent.

These empirical results are consistent with the theoretical models developed by Helpman and Krugman examining the impact of tariffs on terms of trade in imperfectly competitive markets. In a model with differentiated products which consumers view as imperfect substitutes, Helpman and Krugman show that the imposition of a tariff may benefit consumers
and result in lower domestic consumer prices. The tariff makes foreign production less profitable and as foreign firms exit, exports markets expand for domestic firms.

These results confirm an important insight highlighted in Krugman's summary of implications from the strategic trade policy literature. Strategic trade policy model suggest that protection may encourage entry of domestic firms and lead to expanded exports. Both the Nash tariff and pre-NAFTA tariff scenarios result in higher U.S. total social welfare and high domestic onion consumption than the free trade scenario. Producer surplus for onion producers in Mexico is slightly lower under both the Nash tariff and pre-NAFTA tariff. In turn, U.S. onion producers benefit from the expanded export opportunities when tariffs are in place.

**Conclusion**

Incorporating the tariff policies of Canada, Mexico, and the United States into an estimated econometric model, an international trade model for fresh onions was converted to a nonzero-sum finite noncooperative game. The Nash equilibrium of this game was evaluated through a numerical iterative approach. The optimal tariffs, trade flows, prices, and the value of social welfare for each country under the Nash equilibrium were obtained in a manner consistent with market-clearing constraints. To examine the impacts of the North American Free Trade Agreement (NAFTA) on the North American onion industry, a free trade scenario and a scenario with the current tariff rates were evaluated along with that for the Nash equilibrium tariffs. Mexico gains under the free trade scenario, while both Canada and the United States face slight declines in total social welfare relative to the outcomes reflected by the Nash equilibrium tariff rates.
Clearly, free trade was not found to be optimal for all parties. In light of this, it would not be surprising if the game were to continue in kind via nontariff venues such as sanitary and phytosanitary regulations.
Table 1. Results for Free Trade, the Noncooperative Game, and the Pre-NAFTA Tariff Structure for North American Onions

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Free Trade</th>
<th>Nash Tariff</th>
<th>Pre-NAFTA Tariff</th>
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<tr>
<td>Tariffa</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Canada</td>
<td>0.00</td>
<td>0.17</td>
<td>0.10</td>
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<td>Mexico</td>
<td>0.00</td>
<td>0.06</td>
<td>0.10</td>
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<td>United States</td>
<td>0.00</td>
<td>0.09</td>
<td>1.75</td>
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<td><strong>Total Onion Consumptionb</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>4,907.18</td>
<td>4,906.64</td>
<td>4,902.97</td>
</tr>
<tr>
<td>Mexico</td>
<td>12,932.26</td>
<td>12,982.45</td>
<td>12,988.63</td>
</tr>
<tr>
<td>United States</td>
<td>51,866.52</td>
<td>51,948.21</td>
<td>51,957.31</td>
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<tr>
<td>Consumer Surplusc</td>
<td></td>
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<tr>
<td>Canada</td>
<td>6.23</td>
<td>6.18</td>
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<td>Mexico</td>
<td>19.55</td>
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<tr>
<td>United States</td>
<td>307.67</td>
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<td>Producer Surplusc</td>
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<td>Government Revenuec</td>
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<td>United States</td>
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<td>0.612</td>
<td>0.659</td>
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<td>Total Social Welfarec</td>
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<td></td>
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<tr>
<td>Canada</td>
<td>13.49</td>
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<tr>
<td>United States</td>
<td>490.96</td>
<td>500.33</td>
<td>501.06</td>
</tr>
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</table>

aAd valorem tariff rates, except for the U.S. pre-NAFTA tariff which was fixed at $1.75/cwt. (Fuller, Gutierrez, and Capps, 1992).

bIn 1,000 cwt.

cIn millions of 1985 dollars.
REFERENCES


