TRADE POLICY AND PRODUCTIVITY ANALYSES OF APPLE AND ORANGE JUICE MARKETS

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ABSTRACT

The goals of this thesis are to a) analyze the impact of trade liberalization and productivity changes on the apple juice markets in the United States and China and b) examine the effects of tariff reduction and productivity improvements on orange juice markets in the United States, European Union, and Brazil.

Chapter 2 titled “A Strategic Trade Analysis of U.S. and Chinese Apple Juice Market”, examines the effects of a change in the U.S. tariff and Chinese productivity on the apple juice market in the United States and China. Because of high competition from Chinese apple juice processors, the United States imposed an anti-dumping duty on apple juice imports from China to protect the domestic processors. This trade policy benefited U.S. processors, but negatively impacted Chinese processors as well as consumers in the United States. Because of the economic reforms, foreign direct investment, and technological spillover, Chinese apple processors have increased their productivity. Under oligopolistic competition with endogenous firm entry and exit, this chapter analyzes how the changes in U.S. tariff policy and Chinese productivity impact the market structure in the United States and China and prices, quantities, and U.S. and Chinese welfare. Trade liberalization and an increase in Chinese productivity help U.S. consumers and Chinese processors. However, U.S. tariff removal adversely affects U.S. apple juice processors.

Chapter 3 titled “Analysis of Trade Liberalization and Productivity Changes in the Orange Juice Market”, analyzes the oligopolistic competition of Florida and Sao Paulo orange juice processors. Orange juice processors in Florida face stiff competition from São Paulo processors. The United States imposes a specific import tariff to protect the domestic processors, whereas the European Union imposes an ad valorem tariff on orange juice imports. These trade policies benefit Florida processors, but harm São Paulo processors as well as consumers in the United States and the European Union. Under oligopolistic competition with endogenous firm entry and exit, this chapter analyzes how the changes in tariff policy and productivity impact the market structure in Florida and São Paulo and prices, quantities, and welfare in the United States, Brazil, and the European Union. Free trade and an increase in São Paulo productivity help consumers and São Paulo processors. In contrast, U.S. tariff reduction adversely impacts Florida processors.

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DEDICATION

It is a great honor to dedicate this thesis to my major professor **Dr. Stephen Devadoss** for his indomitable guidance, emotional support, and financial assistance during my graduate program. Dr. Devadoss, a truly great and selfless human being, has shaped my future and showed me a successful path for my life.

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CHAPTER 1

INTRODUCTION

1.1 Background

Trade between two countries occurs because of differences in prices of goods. Price differences result from demand and supply differences across countries. Differences in demand are due to tastes and preferences of consumers. Differences in supply occur because of technological differences which is explained by the Ricardian Theory of Comparative Advantage and endowment differences which is covered by the Heckscher-Ohlin Theorem. However, these theories have not accounted for trade arising from economies of scale, imperfect competition, and differentiated products.

From the early 1970s, the literature has progressed to analyze trade between countries with similar technology and factor endowments. This has led to the development of a new trade theory which incorporates imperfect market structure to explain trade between similar countries. Krugman (1979) and Lancaster (1980) established that increasing returns to scale pertaining to each firm in an industry is also a source of trade and that economies of scale will change the direction of comparative advantage. Markusen (1981) constructed a simple two-country model to prove that imperfect market structure can cause trade. He also showed that under Cournot-Nash competition, trade between identical countries will lead to welfare gain. In addition, he ascertained that if countries differ in size, trade will lead to an increase in real world income but could lead to welfare loss for a large country. Brander and Krugman (1983) developed a model of international trade which arises due to rivalry among oligopolistic firms. They also concluded that such trade may lead to dumping and two way trade in similar goods, and such dumping will lead to welfare gain under free entry and Cournot competition. Caves (1985) reviewed the recent contributions to the interface between international trade and industrial organization. He found that import competition places a considerable limit on domestic market power. In the short run, competitive conditions can influence the speed and efficiency of a domestic market's adjustment to international market shocks. He also showed that exports' effects on competition among domestic sellers are unclear and depend on the scope of the price discrimination. Further, he concluded that exposure to trade also increases the technical efficiency of production.

Venables (1985) analyzed the intra-industry trade between economies under the assumption of imperfect competition, homogenous output, increasing returns to scale, and free entry and exit of firms. He showed that such trade augments welfare, reduces the degree of market power, and also increases firm size. Brander and Spencer (1985) showed that under oligopolistic competition, export subsidies can improve the profitability and relative position in non-cooperative rivalries with foreign firms enabling home firms to increase their market share. These subsidies will improve the welfare of the home country at the expense of the foreign country. Horstmann and Markusen (1986) developed a two-country model under the assumptions of increasing returns to scale, perfect or imperfect substitute goods, Cournot-Nash competition, and free entry. They found that restrictive trade policies have negative effects, in contrast to favorable effects under the no entry assumption. They also proved that policies such as import tariffs and exports subsidies will lead to inefficient entry and negative welfare changes. Such trade policy analyses under imperfect competition is termed as "strategic trade policy" in the literature.

In the 1990s, a new trend emerged emphasizing productivity differences among firms in the same industry within a country. This led to development of "New" New Trade Theory. Melitz (2003) concluded that more productive firms flourish in the export market and the least productive firms exit the industry. This theory predicts exit of less productive firms from the industry and increased export sales by the more productive firms will lead to reallocation of market power towards productive firms and that aggregate productivity will increase. In addition, trade protection measures shelter the less productive firms and lead to inefficiency. Melitz and Ottaviano (2008) developed a monopolistic trade model with firm heterogeneity and endogenous market structure and analyzed how the market structure changes in different markets that are not perfectly integrated through trade. They proved that the larger the market, the lower the mark-ups and the higher the aggregate productivity. They also examined the pro-competitive effect of increased import competition and its impact on the profits and productivity in the import market.

The strategic trade theory has been applied to various manufacturing and service industries (Bowen et al., 2012). However, few studies have employed strategic trade policy in agricultural commodities and the food processing sector. Braga and Silber (1991) estimated the impact of U.S. anti-dumping duties against Brazilian frozen concentrated orange juice processors on market power and welfare. They concluded that this anti-dumping duty strengthened the oligopoly-oligopsony relationship among the Brazilian producers and their U.S. counterparts, whereas it has limited the prospect for increased competition in the world orange juice market. Arnade, Pick, and Gopinath (1998) used New Empirical Industrial Organization to demonstrate that firms exhibit oligopoly market power in both domestic and international markets. They empirically tested four industries viz., poultry processing, rice milling, meat processing, and cigarette manufacturing and showed that these industries exhibit oligopoly behavior in either or both markets.

Few studies have also incorporated this new trade theory and estimated market power. Luckstead, Devadoss, and Mittelhammer (2014b) applied new trade theory and new empirical industrial organization literature to examine the degree of market power of U.S. and Chinese apple traders in ASEAN markets and also the impact of trade policies on U.S. and Chinese market power in these nations. Luckstead, Devadoss, and Mittelhammer (2014a) used strategic trade theory and new empirical industrial organization and established that market power does exist in the U.S. and European orange juice industries. They also analyzed and estimated the impacts of U.S. and EU tariff reduction on Florida and São Paulo orange juice processors in the U.S. and EU orange juice markets under oligopolistic competition.

Trade in agricultural commodities has also been augmented due to regional free trade agreements such as North American Free Trade Agreement (NAFTA), South Asian Free Trade Agreement (SAFTA), and Association of South East Asian Nations (ASEAN) through phasing out of various trade restrictions. However, global trade liberalization in agricultural commodities has always involved complexities with a wide imbalance between developed and developing nations. To safeguard the interests of domestic farmers as well as food processing industries, countries have adopted various trade policies. The implementation of these policies are influenced by various factors. For example, different market structure for different products has wide ranging impact on these policies and therefore welfare in these nations. This factor necessitates the incorporation of endogenous market structure in the policy analysis.

This thesis is comprised of two studies: 1) a strategic trade analysis of U.S. and Chinese apple juice markets and 2) a new trade theoretic analysis of trade liberalization and productivity changes in the U.S., Brazilian, and European Union orange juice markets. This thesis advances the literature by endogenously determining the market structure, i.e., the change in the number of firms (processors) resulting from trade liberalization and productivity enhancements and also quantifies the welfare impact of these changes.

1.2 Chapter Summaries

Chapter 2 analyzes the imperfect competition between U.S. and Chinese apple juice processors and also the welfare change under trade liberalization and improvements in productivity. In the late 1980s, China promoted the apple and juice industry. Due to government subsidies and intervention, the apple juice industry has thrived and supply has exceeded demand. The Chinese government promoted the exports of apple juice to western nations such as the United States, European Union, and Canada, which lowered the prices and adversely impacted the producers in these countries. In response to aggressive Chinese exports, the United States imposed an anti-dumping duty on imports to protect the domestic growers and apple juice processors. However the volume of imports continued to increase. In this paper we analyze the impact of U.S. import tariff and productivity changes on prices, quantities, and welfare of producers and consumers in the United States and China.

The objectives of this study are to a) construct a strategic trade model to theoretically examine the effects of a change in the U.S. tariff on the apple juice markets in the United States and China, b) estimate an econometric model and calculate market power, and c) simulate the effect of changes in the U.S. tariffs and Chinese productivity increases on prices, supply, demand, trade, market power, and welfare in the United States and China. The United States consumes all of its apple juice production domestically with negligible exports. In contrast, Chinese firms export almost all of their juice production because of very limited domestic consumption. The model includes free entry and exit of firms using zero-profit conditions to account for endogenous changes in market structure.

The results of this study shows that a reduction in the U.S. tariff decreases the price of Chinese apple juice in the U.S. market. As a result, exports from China to the United States increase. The higher imports from China replace the U.S. domestic processor's apple juice sales in the U.S. market. U.S. consumers benefit from a lower price, which augments consumer surplus. U.S. welfare increases because the gain in consumer surplus exceeds the loss in tariff revenues. With an increase in Chinese productivity relative to U.S. productivity, Chinese production and exports increase. Due to higher exports, Chinese processors find it profitable and more firms enter the industry. With more apple juice entering the United States, price decreases, leading to a gain in consumer surplus. Due to higher imports, tariff revenues rise. Because of the price decline, the profitability of U.S. processors is affected, resulting in exit of firms in the United States. To survive in the industry, U.S. apple juice processors and apple growers should increase their productivity and invest in modern technologies.

Chapter 3 analyzes the impact of changes in U.S. and EU trade polices and São Paulo (Brazil) productivity increases on the number of processors and welfare in the orange juice market in the United States, European Union, and Brazil. In the United States, Florida oranges are mostly used for juice production, and 90% of orange juice is domestically consumed. Similarly, São Paulo is the largest producer of orange juice in Brazil with 99% of production exported. The United States and the European Union are the first and second in the world in terms of per capita consumption with the latter accounting for 58% of world total imports. The United States imposes a tariff on orange juice imports to safeguard the interests of domestic growers and processors. The European Union implements trade restrictions on imports from non-colonial countries. In this study, we analyze how trade liberalization by the United States and European Union will affect the orange juice markets in the United States, European Union, and Brazil.

The objectives of this study are to a) construct a strategic trade model with free entry and exit to analyze the oligopolistic competition of Florida and São Paulo orange juice processors, b) theoretically analyze the impacts of a change in the U.S. and European tariffs on the orange juice markets in the United States, Europe, and Brazil, and c) simulate the effects of U.S. and EU tariff removal and São Paulo productivity increases on the number of processing firms, prices, supply, demand, trade, and welfare in the United States, Brazil, and Europe.

To endogenize the number of firms, we include free entry and exit of firms using zero-profit conditions. From the first-order conditions of profit maximization and zero-profit conditions, we derive a system of simultaneous equations for empirical analysis and we run simulation analysis to solve for endogenous variables under U.S. and EU tariff reductions and São Paulo productivity changes. We also compute welfare changes from these trade liberalizations.

The study shows that a reduction in the U.S. tariff decreases the orange juice price in the U.S. market. As a result, exports from São Paulo to the United States increase, and Florida sales and the number of firms decline. U.S. consumers benefit due to lower prices. U.S. welfare increases because the gains in consumer surplus exceeds the loss in tariff revenues. With U.S. tariff elimination, São Paulo diverts its exports from the European Union to the United States, leading to a higher price, less consumption, a decline in consumer surplus, a reduction in tariff revenues, and welfare loss.

EU tariff removal lowers the price of São Paulo's orange juice in the European Union and increases exports from São Paulo. EU consumers gain. With removal of the tariff, EU tariff revenue is lost. As more is exported to the European Union, São Paulo diverts its exports from the United States to the European Union, causing Florida's sales and the number of processors to increase. However, total sales in the United States decline, which leads to a rise in the orange juice price, resulting in lower consumer surplus. Welfare declines as consumer surplus and tariff revenues fall.

With an increase in São Paulo productivity, exports to both the United States and the European Union increases, resulting in an increase in the number of processors in São Paulo. Florida's output decreases, leading to exit of orange juice processors. Due to more imports, price decreases and consumption increases, resulting in a gain in consumer surplus in both the United States and the European Union. Consequently, there is a net welfare gain in both of these countries.

CHAPTER 2

STRATEGIC TRADE ANALYSIS OF THE U.S. AND CHINESE APPLE JUICE MARKET

2.1 Introduction

In the last two decades, the U.S. apple juice industry has been dominated by a small number of processors in the United Sates and China. This concentration has likely led to oligopolistic competition in the U.S. apple juice industry among U.S. and Chinese processors.

While the U.S. apple juice industry has been stable for several decades due to a well established apple production system, the Chinese apple juice industry has experienced rapid growth since the late 1990s due to several factors. In the early 1980s, the Chinese government promoted apple production in the underdeveloped the highlands of the Loess plateau in the Northwest and the highlands of the Southwest to improve the livelihood of local farmers. The government provided subsidies for inputs like apple saplings, fertilizer, pesticides, and loans to augment apple production (Zai-Long, 1999). Due to favorable climate, high yields, and government support, apple acreage and production have increased by 4.2 and 7.5 times, respectively, in the last two decades. As a result, supply outpaced domestic demand. In 1990, to alleviate the excess apple supply, the Chinese government encouraged investment in the apple processing industry. Since 1992, through the investment of multinational firms and the Chinese government, the industry expanded apple juice production, which rapidly exceeded domestic demand prompting the government to promote exports. Currently, there are five major apple juice processors who control 72% of the total Chinese apple juice exports (Gale, 2011). Due to cheaper labor and apples and conducive government policies, the Chinese share of the world apple juice market has increased from 0% in 1991 to 49% in 2009. This led to a geographical shift in the concentration of the apple juice industry.

China has become the largest producer of apple juice, followed by the United States and Poland. With low domestic demand, Chinese apple juice processors export more than 90% of their production. In contrast, the United States and Poland export a very small amount of apple juice due to high U.S. and EU consumption. China exported 40% of their total exports to the United States, 20% to the European Union and 10% to Japan during 2007-2009 (Gale, 2011).

Because of a cheaper price, the United States started importing more from China which displaced imports from other countries such as Chile, Argentina, Mexico, and the European Union, and has led to 47% decline in domestic U.S. production since 1992. Consumption in the United States has increased from 350 million single strength equivalent (SSE) gallons in 1986 to around 667 million SSE gallons in 2009. Consequently, the share of U.S. production in U.S. consumption declined from 37% in 1986 to 15% in 2009. With consolidation of the industry as a result of increased competition and market saturation, only five major apple juice processors are operating in the United States (Data-Division-USAPA, 2014).

Cheaper imports and intense competition from Chinese exporters have put downward pressure on U.S. apple juice production, as shown in Figure 1. Specifically, Chinese apple juice exports to the United States increased from 20.71 million SSE gallons in 1997 to 451.35 million SSE gallons in 2009. During this period, U.S. apple juice production steadily declined from 168.6 million SSE gallons to 100.3 million SSE gallons, affecting the profitability of both processors and apple growers. This prompted the United States to impose an anti-dumping duty of 4.91 cents per SSE gallon in 1999 (World Trade Organization, 2014). However, imports from China continued to increase, contributing to about two-thirds of total supply during the period 2007-2009.

Few studies have analyzed the U.S. and Chinese apple juice industry and trade under the assumption of perfect competition. For example, van Voorthuizen et al. (2001) analyzed the impact of the U.S. anti-dumping duty on Chinese apple juice on Washington state apple juice processors' revenues. They also estimated the demand for apple juice and the intermediate input, i.e., apples. Rowles (2001) studied the U.S. processed apple markets and found that growers and processors face numerous challenges owing to new market conditions. He also concluded that only low-cost and productive firms will survive in the industry and less competitive firms will exit the industry. Fonsah and Muhammad (2008) analyzed the demand for

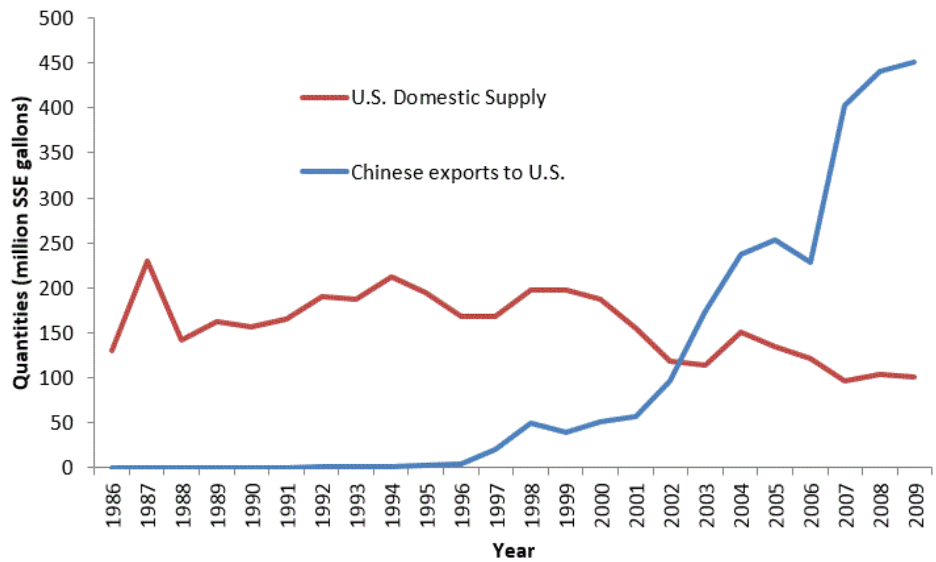

Figure 1: Apple Juice: U.S. Domestic Supply and Chinese Exports to the United States

imported apple juice in the United States and they concluded that U.S. imports from Argentina, Chile, and the rest of the world (ROW) were highly sensitive to Chinese apple juice prices. Chinese exports to the United States were impacted by prices in Argentina, Chile, and the rest of the world. However, the responsiveness of imports from China to apple juice prices in these countries was relatively smaller than the responsiveness of imports from these countries to the Chinese price. Mekonnen and Fonsah (2011) estimated the U.S. import demand for apple juice using restricted source differentiated Almost Ideal Demand System model and found that U.S. demand for apple juice from China is inelastic and expenditure elasticity is relatively high.

Devadoss, Ridley, and Sridharan (2012) constructed a spatial equilibrium model of world apple and apple juice markets to quantify the effects of tariff removal on these markets. Their results showed that trade liberalization had considerably higher impact on apple trade than juice trade. They also found that exporting countries such as the United States, Poland, and China and importing countries such as India and Russia gain from this trade liberalization. Luckstead, Devadoss, and Mittelhammer (2014b) utilized New Trade Theory and New Empirical Industrial Organization to examine the degree of market power of U.S. and Chinese apple traders in ASEAN markets and also the impact of trade policies on U.S. and Chinese market share in these nations.

The current study advances the literature on the apple juice industry by analyzing the imperfect competition among U.S. and Chinese apple juice processors and the impact of trade policies and productivity changes on the apple juice markets and endogenizing the market structure through endogenous firm entry and exit.

The objectives of this study are to 1) construct a strategic trade model of U.S. and Chinese apple juice markets, 2) theoretically examine the effects of a change in the U.S. tariff on the apple juice market in the United States and China, 3) estimate an econometric model and calculate the market power and supply and demand elasticities, and 4) simulate the effect of exogenous changes in U.S. tariffs and an increase in Chinese apple juice productivity on prices, trade, and welfare in the United States and China.

2.2 Theoretical Model and Analysis

New Trade Theory purports that trade between countries having similar endowments and technology takes place because of economies of scale, distorted market structure, and differentiated goods. For instance, Krugman (1979) found that due to differences in economies of scale, distorted market structure exists. He also established that trade and gains from trade will occur between countries with similar tastes and preferences, technology, and factor endowments. Later studies (Dixit and Norman, 1980; Krugman, 1980; Helpman, 1981; Brander and Krugman, 1983) incorporated oligopolistic competition and monopolistic competition into trade models to analyze reciprocal dumping, intra-industry trade, etc. A pioneering study by Melitz (2003) showed that productivity differences among firms lead to trade, and highly productive firms engage more in trade. He also found trade barriers buffer the less productive firms and elimination of such barriers result in welfare gain. Melitz and Ottaviano (2008) developed a monopolistic competition trade model with firm heterogeneity and endogenous market structure to analyze how market structure changes in different markets that are not perfectly integrated through trade.

This led to development of new New Trade Theory (NNTT) which emphasizes patterns of trade and welfare due to firm-level differences in productivity.

Few studies have examined imperfect competition under trade protection and expansionary policies in agricultural commodity markets. Luckstead, Devadoss, and Mittelhammer (2014a) analyzed imperfect competition between Florida and São Paulo processors under different trade policies using strategic trade theory.

In this section, we develop a strategic trade model with zero profit conditions for U.S. and Chinese apple juice markets based on the market structure outlined in the Introduction. The firm-level profit function of U.S. apple juice processors is given by

$$\pi^{US} = p^{US}\left(Q^{UD} + Q^{CU}\right) q^{UD} - C^{UD}\left(q^{UD}; \omega^{U}\right) - f^{U}, \tag{1}$$

where p^{US} is the price of apple juice in the U.S. market, $p^{US}\left(Q^{UD} + Q^{CU}\right)$ is the U.S. inverse demand function, Q^{UD} is the quantity of apple juice sold by U.S. processors in the United States, Q^{CU} is the quantity of apple juice sold by Chinese processors in the United States, q^{UD} is the firm-level output, $C^{UD}\left(q^{UD}; \omega^{U}\right)$ is the variable cost function, ω^{U} is the productivity parameter associated with apple juice production, and f^{U} is the fixed cost.

The Chinese firm-level profit function is given by

$$\pi^{C} = \left(p^{US}\left(Q^{UD} + Q^{CU}\right) - \tau^{U}\right) q^{CU} + \tilde{p}^{CO}\tilde{q}^{CO} - C^{C}\left(q^{CU} + \tilde{q}^{CO}; \omega^{C}\right) - t^{U} q^{CU} - f^{C}, \tag{2}$$

where τ^{U} is the specific tariff imposed by the United States, q^{CU} is the firm-level output sold in the United States, $\tilde{p}^{CO}$ is the price of Chinese apple juice exports to the rest of the world (excluding the United States) adjusted for transport cost, $\tilde{q}^{CO}$ is the firm-level output sold by Chinese processors in the rest of the world, $C^{C}\left(q^{CU} + \tilde{q}^{CO}; \omega^{C}\right)$ is the variable cost function, ω^{C} is the firm-level productivity parameter in apple juice production, t^{U} is the transport cost of shipments from China to the United States, and f^{C} is the fixed cost.

We obtain the first-order conditions by differentiating the profit functions (1) and (2) with respect to q^{UD} and q^{CU}, respectively. They are rearranged to obtain reaction functions:

$$\pi^{US}_{q^{UD}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD} + Q^{CU}\right)}{\partial\left(Q^{UD} + Q^{CU}\right)} + p^{US}\left(Q^{UD} + Q^{CU}\right) - \frac{\partial C^{UD}\left(q^{UD}; \omega^{U}\right)}{\partial q^{UD}} = 0 \tag{3}$$

$$\pi^{C}_{q^{CU}} = q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} + \left(p^{US}-\tau^{U}\right) - \frac{\partial C^{CU}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}} - t^{U} = 0. \quad (4)$$

To endogenize the number of firms, we specify the zero-profit conditions by incorporating the number of processors and rewriting the aggregate quantities as firm-level quantity times the number of processors ($Q^{UD} = N^{U}q^{UD}$ and $Q^{CU} = N^{C}q^{CU}$), where N^{U} and N^{C} are the number of U.S. and Chinese processors respectively:

$$\pi^{OUS} = p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)q^{UD} - C^{UD}(\cdot) - f^{U} = 0 \quad (5)$$

$$\pi^{OC} = \left(p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)-\tau^{U}\right)q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - C^{C}(\cdot) - t^{U}q^{CU} - f^{C} = 0. \quad (6)$$

Since the demand functions are downward sloping and we consider a convex cost function, the reaction functions will yield a solution because the profit functions are globally concave implying the second-order conditions for a maximum are satisfied. With specific functional forms for demand and cost functions, we can solve the above four equations (3) - (6) simultaneously for four endogenous variables q^{UD}, q^{CU}, N^{U}, and N^{C}. To maintain generality, we consider general functional forms and totally differentiate these four equations to conduct comparative static analysis of policy changes.

2.2.1 Comparative Statics

In this section, we analyze the impact of a reduction in the U.S. tariff (τ^{U}) and changes in productivities (i.e., changes in ω^{C} relative to ω^{U}) on quantities and number of firms. We totally differentiate the equations (3) - (6) and represent them in the matrix form $Ax = d$:

$$\begin{bmatrix} \pi^{US}_{q^{UD}q^{UD}} & \pi^{US}_{q^{UD}q^{CU}} & \pi^{US}_{q^{UD}N^{U}} & \pi^{US}_{q^{UD}N^{C}} \\ \pi^{C}_{q^{CU}q^{UD}} & \pi^{C}_{q^{CU}q^{CU}} & \pi^{C}_{q^{CU}N^{U}} & \pi^{C}_{q^{CU}N^{C}} \\ \pi^{OUS}_{q^{UD}} & \pi^{OUS}_{q^{CU}} & \pi^{OUS}_{N^{U}} & \pi^{OUS}_{N^{C}} \\ \pi^{OC}_{q^{UD}} & \pi^{OC}_{q^{CU}} & \pi^{OC}_{N^{U}} & \pi^{OC}_{N^{C}} \end{bmatrix} \begin{bmatrix} dq^{UD} \\ dq^{CU} \\ dN^{U} \\ dN^{C} \end{bmatrix} = - \begin{bmatrix} \pi^{US}_{q^{UD}\omega^{U}}d\omega^{U} \\ \pi^{C}_{q^{CU}\tau^{U}}d\tau^{U} + \pi^{C}_{q^{CU}\omega^{C}}d\omega^{C} \\ \pi^{OUS}_{\omega^{U}}d\omega^{U} \\ \pi^{OC}_{\tau^{U}}d\tau^{U} + \pi^{OC}_{\omega^{C}}d\omega^{C} \end{bmatrix}.$$

The determinant of A is positive. We can analyze the effect of a change in τ^{U} and ω^{C} on q^{UD}, q^{CU}, N^{U}, and N^{C} by applying Cramer's rule. See the Appendix for derivations of selected comparative statics. However, the comparative static results are ambiguous because of the opposite effects of various terms. Consequently, we quantify the effects of changes in τ^U and ω^C in the empirical analysis section.

2.2.2 Welfare Analysis

In this section, we examine the impacts of a reduction in the U.S. tariff and productivity changes on U.S. and Chinese welfare. U.S. welfare is comprised of only consumer surplus and tariff revenues because producer surplus in zero due to the zero-profit condition:

$$W^{US}\left(Q^{US};\tau^U,\omega^U,\omega^C\right)=\underbrace{\left\{\int p^{US}\left(Q^{US}\right)dq^{US}-p^{US}\left(Q^{US}\right)Q^{US}\right\}}_{\text{Consumer Surplus}}+\underbrace{\tau^U Q^{CU}}_{\text{Tariff Revenue}}. \tag{7}$$

Total U.S. consumption is given by $Q^{US}=Q^{UD}+Q^{CU}$. The Chinese welfare is zero since producer surplus is zero because of the zero-profit condition and zero consumer surplus as there is no domestic consumption.

Welfare Analysis of Reduction in U.S. tariff

We totally differentiate (7) with respect to τ^U to determine the effects of a reduction in the U.S. tariff on U.S. welfare. The change in U.S. welfare is given by:

$$\frac{dW^{US}(\cdot)}{d\tau^U}=\underbrace{-\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial \tau^U}Q^{US}}_{\text{CS}(-)}+\underbrace{Q^{CU}\left(1+\frac{\partial Q^{CU}}{\partial \tau^U}\frac{\tau^U}{Q^{CU}}\right)}_{\text{TR}(?)}. \tag{8}$$

Chinese exports to the United States increase due to a reduction in the U.S. import tariff, resulting in a lower U.S. apple juice price. The United States experiences a gain in consumer surplus (CS) because of higher consumption. However, the change in tariff revenues (TR) could be positive or negative depending on whether the import demand curve is inelastic or elastic. Hence the net welfare effect could be positive or negative. However, since the gain in consumer surplus will most likely outweigh the loss in tariff revenues, U.S. welfare is likely to increase.

A reduction of the U.S. tariff leads to cheaper Chinese exports to the United States which displaces the domestic processors' sales, adversely affecting profitability. As a result, firms exit the industry until profits turn non-negative. Due to an increase in exports, profitability of Chinese firms goes up in the short-run, which results in entry of more firms in the Chinese apple processing industry.

Welfare Analysis of Change in Chinese Productivity

Due to trade liberalization, firms in both the United States and China compete against each other. As a result of foreign direct investment and conducive trade policies, Chinese firms acquire modern processing technology, leading to an increase in apple juice production. The effect of this increase in Chinese productivity on U.S. welfare is

$$\frac{dW^{US}(\cdot)}{d\omega^C} = \underbrace{-\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial \omega^C}Q^{US}}_{\text{CS}(+)} + \underbrace{\tau^U\frac{\partial Q^{CU}}{\partial \omega^C}}_{\text{TR}(+)} \tag{9}$$

With higher output, Chinese processors augment their exports to the United States. Higher imports from China result in a lower U.S. apple juice price leading to higher U.S. consumption and hence a gain in consumer surplus. As imports rise, tariff revenue accrued to the U.S. government increases. Hence the net change in U.S. welfare is positive.

Because an increase in Chinese firms' productivity leads to more exports to the United States, the sales of U.S. processors decline and their profits go down. This results in exit of U.S. firms from the apple juice industry. With higher exports due to higher production, more firms enter the Chinese industry.

2.3 Empirical Model and Analysis

In this section, we derive the econometric model from the theoretical results, describe and discuss data and sources, present the econometric estimates, simulation analysis, and results.

2.3.1 Econometric Model

Though China exports 44% of its total apple juice production to the United States, the remaining exports go to many other countries. Since exports to each of these countries are small relative to that of the United States, these exports are treated as exogenous. Similarly, the United States imports from other countries such as Chile, Argentina, and Mexico. Since imports from each of these countries are a small percentage of total U.S. imports, they are also treated as exogenous. We therefore maintain focus on the key players in the U.S. apple juice industry. The two supply relations for econometric model are specified by rewriting the first-order conditions (3) and (4):

$$p^{US} = \frac{\partial C^{UD}(\cdot)}{\partial q^{UD}} + \psi^{US}\xi^{US}p^{US} = 0 \tag{10}$$

$$p^{US} = \frac{\partial C^{C}(\cdot)}{\partial q^{CU}} + t^{U} + \psi^{CU}\xi^{US}p^{US} + \tau^{U} = 0, \tag{11}$$

where $\psi^{US} = \frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}\frac{q^{UD}}{\left(Q^{UD}+Q^{CU}\right)}$ is the conjectural elasticity of a U.S. domestic firm, $\xi^{US} = -\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}$ is the flexibility of demand in the U.S. market, and $\psi^{CU} = \frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}\frac{q^{CU}}{\left(Q^{UD}+Q^{CU}\right)}$ is the conjectural elasticity of a Chinese firm exporting to the United States. The conjectural elasticities $\left(\psi^{US}\text{ and }\psi^{CU}\right)$ vary from zero to one. Mark up ($\psi^{i}\xi^{US}p^{US}$, $i = US, CU$) depends on conjectural elasticities, demand flexibility of the particular firm, and price.

We specify demand and cost functions, and consider the conjectural elasticities to derive supply relations. The marginal cost functions for U.S. and Chinese processors are given by

$$mc^{UD} = \frac{\partial C^{UD}}{\partial q^{UD}} = \lambda_0^{UD} + \lambda_1^{UD}q^{UD} \tag{12}$$

$$mc^{C} = \frac{\partial C^{C}}{\partial q^{CU}} = \lambda_0^{C} + \lambda_1^{C}\left(q^{CU} + \tilde{q}^{CO}\right), \tag{13}$$

where λ_i^js are marginal cost coefficients ($i = 0, 1$; and $j = UD, CU$). Next, we specify the U.S. demand function

$$p^{US} = \mu_0^{US} + \mu_1^{US}\left(Q^{UD} + Q^{CU}\right) + \boldsymbol{\mu}^{US}\mathbf{Z}^{US}, \tag{14}$$

where μ_i^{US}s ($i = 0, 1$) are demand coefficients, $\boldsymbol{\mu}^{US}$ is a vector of coefficients, and $\mathbf{Z}^{US}$ is a vector of demand shifters.

Using the redefined first-order conditions (10) and (11), marginal cost functions (12) and (13), demand flexibilities, and conjectural elasticities, the supply relations of U.S. and Chinese processors are given by

$$p^{US} = \lambda_0^{UD} + \lambda_1^{UD}Q^{UD} + \psi^{US}\mu_1^{US}\left(Q^{UD} + Q^{CU}\right) \tag{15}$$

$$p^{US} = \lambda_0^{C} + \lambda_1^{C}\left(Q^{UD} + \tilde{Q}^{CO}\right) + t^{U} + \psi^{CU}\mu_1^{US}\left(Q^{UD} + Q^{CU}\right) + \tau^{U}. \tag{16}$$

To account for the structural shift in U.S. domestic production and Chinese exports to the United States as shown in Figure 1, a drift variable has been incorporated into the supply relations since the structural shifts in the supply will have considerable impact on degree of market power. The U.S. domestic supply relation is given by

$$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} Q^{UD} + (\zeta_1 + \zeta_2 Drift)\, \mu_1^{US} \left(Q^{UD} + Q^{CU}\right) \tag{17}$$

The conjectural elasticity ψ^{US} is rewritten as $\psi^{US} = (\zeta_1 + \zeta_2 Drift)$, where $\zeta_1 = \frac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{UD}} \frac{q^{UD}}{\left(Q^{UD} + Q^{CU}\right)}$, $\zeta_2 = \frac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{UD}} \frac{q^{UD}}{\left(Q^{UD} + Q^{CU}\right)} Drift$, and $Drift = \frac{t - t_0}{t_f - t_0} I_{(t_0, t_f]}(t) + I_{(t_f, t_N]}$.

Similarly the Chinese export relation to the United States is given by

$$p^{US} = \lambda_0^{C} + \lambda_1^{C} \left(Q^{CU} + \tilde{Q}^{CO}\right) + t^U + (\varphi_1 + \varphi_2 Drift)\, \mu_1^{US} \left(Q^{UD} + Q^{CU}\right) + \tau^U \tag{18}$$

The conjectural elasticity ψ^{CU} is rewritten as $\psi^{CU} = (\varphi_1 + \varphi_2 Drift)$, where $\varphi_1 = \frac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{CU}} \frac{q^{CU}}{\left(Q^{UD} + Q^{CU}\right)}$, $\varphi_2 = \frac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{CU}} \frac{q^{CU}}{\left(Q^{UD} + Q^{CU}\right)} Drift$, and $Drift = \frac{t - t_0}{t_f - t_0} I_{(t_0, t_f]}(t) + I_{(t_f, t_N]}$.

The time-dependent drift variable is given by $Drift = \frac{t - t_0}{t_f - t_0} I_{(t_0, t_f]}(t) + I_{(t_f, t_N]}$ where t is time, t_0 and t_f indicate the beginning and end of the structural shifts, and t_N is the end of the sample period. $I(t_0, t_f] = 1$ for the period $t_0 < t \leq t_f$ and zero otherwise, and $I(t_f, t_N] = 1$ for the period $t_f < t \leq t_N$ and zero otherwise. Based on Figure 1 t_0 =1992, t_f =1999, and t_N =2009 were identified.

To identify parameters in the econometric equations (14), (17), and (18), the number of right-hand side variables in an equation must be equal to or less than the number of exogenous variables excluded from the respective equation (Griffiths et al., 1993). In our econometric model, the parameters of the U.S. domestic and Chinese export supply relations including market power parameter can be identified if the number of the excluded exogenous variables exceed the endogenous variables in the equation. Similarly, this counting rule for identification can be applied to the U.S. demand equation to check if demand parameters are identified.

2.3.2 Data

This study covers the period of 1986-2009. U.S. apple juice production, total consumption, and import data were collected from USDA-NASS (2014) and the U.S. Census Bureau (2014). Chinese exports to the United States and the rest of the world were collected from the FAO-STAT (2014). The data for apple juice concentrate were converted from tons to single strength equivalent gallons. U.S. price data for apple juice concentrate was obtained from the Data-Division-USAPA (2014) for the period 1996-2011. The price data was backcast for the years 1986-1995 using the concentrated juices price index. The consumer price index for the United States was gathered from World Bank Countrywise Macroeconomic Statistics (World Bank, 2014) and used for adjusting the nominal prices of apple juice to real prices.

Input prices for wage, machinery, capital, and energy for the fruit processing industry were collected from the Manufacturing Productivity Database of Data-Division-NBER (2014) and were converted to indices to ensure uniformity in the units of magnitude in the data. Similarly Chinese input price indices for wages, machinery, capital, and fuel were collected from the National Bureau of Statistics of China. The intermediate input prices for apples for the United States and China were obtained from the FAOSTAT (2014).

The data for demand shifters such as U.S. population and national income were gathered from the World Bank Countrywise Macroeconomic Statistics (World Bank, 2014), and the national income was adjusted using the consumer price index to reflect the real income. Orange juice was chosen as the substitute good, the another demand shifter and the U.S. demand for orange juice was obtained from the Commerce Division, U.S. Census Bureau.

The U.S. antidumping duty on China was imposed during the year 1999 at 4.9 cents per gallon for our estimation (WTO, 2014). The transportation cost data was calculated as the difference between Free on Board (FOB) values and Cost, Freight, and Insurance (CIF) values of Chinese exports to the United States.

2.3.3 Estimation

From the empirical model, the demand equation (14) and two supply relations (17) and (18) are specified. For econometric estimation, we use non-linear three stage least squares to solve for the parameters. We also introduce bounds and restrictions for the conjectural elasticities to ensure that these parameters are between zero and one, which is consistent with economic intuition. Table 1 summarizes the variable definitions.

Table 1: Variable Definitions

Variables	**Definitions**
P^{US}	U.S. apple juice price, $ per SSE gallon
Q^{US}	U.S. total consumption, 100 million SSE gallons
Q^{UD}	U.S. domestic supply, 100 million SSE gallons
$USRInc$	U.S. real income in trillions, USD
$USPop$	U.S. population, 100 millions
$QUSOJ$	U.S. orange juice consumption, 100 million SSE gallons
$PC1US$	Principal component for vector of U.S. input indices
$Drift$	Drift variable for U.S. supply and Chinese exports to the United States
ζ_1	Intercept of drift variable for U.S. domestic supply
ζ_2	Slope of drift variable for U.S. domestic supply
φ_1	Intercept of drift variable for Chinese exports to the United States
φ_2	Slope of drift variable for Chinese exports to the United States

Table 2 presents the econometric estimation results of the U.S. demand and supply coefficients. The estimated values of demand coefficients have the right signs and are consistent with economic intuition. The estimate of the slope coefficient is significant at the 1% level. Similarly, estimates of coefficients for the U.S. supply relation such as principal components and drift variables have the right signs and corroborate economic theory. For the United States, domestic production contributed about 40% of its total consumption in the early 1990s, but has gone down to 15% in 2009 which is reflected in the estimates of the drift variables for the domestic supply. The drift intercept ζ_1 reached its upper bound, indicating that before China entered the U.S. apple juice market, U.S. processors had a high level of control over the U.S. price.

However, because the drift slope ζ_2 is negative as Chinese exporters gained market share, U.S. processors' ability to exert market power declined to 0.818 by the end of the structural change.

Table 2: U.S. Demand Function and Supply Relation

Variables	**Estimates**	**Standard Error**
Demand Function		
$Intercept$	1.413	1.001
Q^{US}	-0.227	0.008
$USRInc$	0.005	0.076
$USPop$	0.249	0.557
$QUSOJ$	-0.008	0.015
Supply Relation		
$Intercept$	1.601	0.457
Q^{UD}	0.094	0.158
$PC1US$	0.103	0.128
ζ_1	1.000	$-$
ζ_2	-0.182	0.130

Table 3 presents the estimation results of supply coefficients of Chinese exports to the United States. The results shows that they are statistically significant and consistent with economic intuition.

Table 3: Chinese Export Relation to the United States

Variables	**Estimates**	**Standard Error**
Supply Relation		
$Intercept$	1.205	0.625
Q^{CU}	-0.044	0.017
$PC1Ch$	-0.277	0.366
φ_1	0.105	0.516
φ_2	0.894	0.516

Table 4 represents U.S. demand flexibilities and conjectural elasticities of U.S. and Chinese processors. The U.S. demand flexibility has increased from -1.24 to -2.44 which implies that U.S. demand for apple juice has become relatively inelastic, i.e., the degree of responsiveness of U.S. apple juice demand to a change in price has declined.

Table 4: U.S. and Chinese Flexibilities and Conjectural Elasticities

Year	U.S. Demand Flexibility (ξ^{US})*	U.S. Conj. Elasticity (ψ^{US})	Chinese Conj. Elasticity (ψ^{CU})	Lerner Index U.S.	Lerner Index China
$t_0 = 1992$	1.24	1.00	0.10	1.24	0.12
$t_f = 1999$	1.51	0.98	0.18	1.48	0.27
$t_N = 2009$	2.44	0.81	1.00	1.98	2.44
*Flexibilities are reported as absolute values.					

The conjectural elasticity for the United States which denotes the responsiveness of aggregate quantity to a change in firm-level quantity has decreased from 1.00 in 1992 to 0.98 in 1999 and to 0.81 in 2009, which is calculated using $\zeta_1 + \zeta_2 Drift$ from equation (17). This implies that the market share of U.S. processors in the U.S. apple juice market has declined. However, the conjectural elasticity of Chinese processors has increased steeply from 0.10 in 1992 to 0.18 in 1999 and to 1.00 in 2009, which is calculated using $\varphi_1 + \varphi_2 Drift$ from equation (18). These results imply that Chinese processors have more control over the U.S. market in 2009 compared to 1999 and 1991.

The last two columns of Table 4 report the Lerner Index for the U.S. and Chinese processors, which are computed by reexpressing (10) and (11) as

$$\frac{p^{US} - \dfrac{\partial C^{UD}(\cdot)}{\partial q^{UD}}}{p^{US}} = \psi^{US}\xi^{US}$$

$$\frac{p^{US} - \dfrac{\partial C^{C}(\cdot)}{\partial q^{CU}} - t^U - \tau^U}{p^{US}} = \psi^{CU}\xi^{US}.$$

Thus the Lerner Index is the demand flexibility times the conjectural elasticity and measures the percent markup of price over marginal cost (adjusted for tariff and transport cost for China). The results show that the Lerner Index for U.S. processors increases from 1.24 to 1.98 from 1992 to 2009. Even though the conjectural elasticity decreases, because the demand flexibility increases, the Lerner Index rises over the study period, which allows U.S. processors to exert greater market power. Similarly, the Lerner Index for Chinese processors increases from

0.12 to 2.44 during the same period. This increase is largely attributed to China increasing its production, augmenting exports, and capturing greater market share in the United States.

2.3.4 Simulation

With the progress of the Doha Round, free trade in commodities between China and the United States will likely occur. Hence it is necessary to analyze the impact of free trade on the prices, quantities, and welfare. Also because of free trade, improved technology in apple juice production can spill over from the United States to China, augmenting Chinese apple juice productivity and hence production. With an increase in production, Chinese exports will increase, and the United States will consume more apple juice. Thus, this increase in productivity also calls for welfare analysis. In addition, since an increase in Chinese exports alters sales in the United States, and their market share, we also incorporate the changes in market power in this analysis. In this section, we analyze the impact of U.S. tariff elimination and an increase in Chinese productivity relative to U.S. productivity on prices, production, trade, market structure, and welfare through simulation analysis.

In the simulation analysis, since we are endogenizing the number of firms, two zero-profit conditions are added to the demand equation and two supply relations. The five equations are redefined by rewriting the aggregate quantity as firm-level quantity times the number of firms. The system of equations for simulation analysis are:

$$p^{US} = \mu_0^{US} + \mu_1^{US}\left(N^U q^{UD} + N^U q^{CU}\right) \tag{19}$$

$$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} Q^{UD} + \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^U q^{CU}\right) \tag{20}$$

$$p^{US} = \lambda_0^{C} + \lambda_1^{C}\left(N^C q^{UD} + \tilde{Q}^{CO}\right) + t^U + \psi^{CU}\mu_1^{US}\left(N^U q^{UD} + N^U q^{CU}\right) + \tau^U \tag{21}$$

$$\pi^{OUS} = p^{US} q^{UD} - \lambda_0^{UD} q^{UD} - \frac{\lambda_1^{UD}}{2}\left(q^{UD}\right)^2 - f^U = 0 \tag{22}$$

$$\begin{aligned} \pi^{OC} = {} & \left(p^{US} - \tau^U\right) q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - \lambda_0^C q^{CU} - \frac{\lambda_1^C}{2}\left(q^{CU}\right)^2 \\ & -\lambda_1^C q^{CU} q^{CO} - \frac{\lambda_1^C}{2}\left(q^{CO}\right)^2 - f^C. \end{aligned} \tag{23}$$

Table 5: Impacts of Tariff Elimination and Productivity Changes

Variables	$\boldsymbol{\tau^U = 0}$	$\triangle\omega^C$
U.S. price (% change)	-2.41	-16.75
U.S. Quantity (% change)	-1.85	-12.82
Chinese exports to the U.S. (% change)	3.31	22.91
Change in Number of Firms in U.S.	-1.00	-1.00
Change in Number of Firms in China	1.00	1.00
Change in Total welfare ($ m)	-5.50	81.30
Change in U.S. consumer surplus ($ m)	11.30	3.10
Change in Tariff Revenue ($ m)	-16.80	78.20

Using the above system of five equations, we solve for five unknowns (p^{US}, q^{UD}, q^{CU}, N^U, and N^C) simultaneously using simulation analysis. Table 4 presents the results of simulation analysis for U.S. tariff elimination and a change in Chinese productivity.

U.S. Tariff Elimination: Removal of the tariff by the United States causes Chinese exports to the United States to increase by 3.31%. With increase in imports, U.S. apple juice price declines by 2.41%. Due to cheaper imports, the profitability of U.S. processors is affected and U.S. domestic production falls by 1.85%. Consequently, one U.S. firm exits the apple juice industry. Apple juice sales by U.S. processors are replaced by Chinese processors since they have a comparative advantage in the cost of production. As a result, one Chinese firm enters the apple juice industry.

With a lower price, consumption in the United States increases, and hence consumer surplus goes up $11.30 million. Due to elimination of the tariff, tariff revenues fall by $16.80 million. This results in a net welfare loss of $5.50 million.

Increase in Chinese Productivity: With an increase in Chinese processors' productivity relative to U.S. processors' productivity, China increases its apple juice production, and hence exports more to the United States. Chinese exports to the United States rise by 22.91%. With cheaper imports, the price of apple juice in the United States decreases by 16.75%. This affects the sales of domestic processors in the United States, whose production declines by 12.82%. This causes one U.S. processor to exit the industry. Since, Chinese processors find it profitable to produce and export, one firm enters the industry.

Consumption in the United States increases as a result of the lower price, leading to a gain in consumer surplus of $3.10 million. With higher imports, tariff revenues increases by $78.20 million. Since the United States experiences a gain in both consumer surplus as well as tariff revenues, the total welfare gain is $81.30 million. These results corroborate the comparative static theoretical results of the welfare analysis.

2.4 Conclusions

The United States is one of the leading consumers of apple juice in the world accounting for about 36% of total world apple juice imports in 2009. In recent years, the U.S. apple juice industry has consolidated its production, and fewer processors produce apple juice. Due to government support and foreign direct investments, the apple juice industry in China has experienced rapid growth, resulting in a geographical shift in the concentration of the apple juice industry. This has led to oligopolistic competition with a few firms exerting market power over sales and prices. The United States is a leading importer of apple juice from China, and has imposed an anti-dumping duty on apple juice imports from China.

We formulate a strategic trade model of the U.S. and Chinese apple juice markets based on new trade theory. We endogenize firm entry and exit by incorporating zero-profit conditions for U.S. and Chinese apple juice processors. We theoretically analyze the effects of changes in the U.S. tariff and a productivity shock on the apple juice market. From the theoretical results, we derive an econometric model for U.S. demand, U.S. domestic supply relation, and Chinese export supply relation. This econometric model is estimated using non-linear three stage least squares. Using the econometric estimation, we compute U.S. demand flexibilities and conjectural elasticities of U.S. and Chinese processors. To analyze the impact of free trade and changes in Chinese processors' productivity relative to U.S. processors' productivity, we conduct a simulation analysis. In addition to the three equations specified for the econometric model, we also incorporate two zero-profit conditions since we are endogenizing the number of firms. Using the system of 5x5 simultaneous equations, we solve for the endogenous variables: U.S. apple juice price, U.S. domestic supply, Chinese exports to the United States, and the number of U.S. processors and Chinese processors. The results show that elimination of the U.S. tariff leads to more U.S. imports from China, resulting in a decrease in the U.S. price and an increase in U.S. welfare. U.S. tariff removal causes one firm to enter in China and one firm to exit in the United States. Higher Chinese apple juice productivity results in more production and exports to the United States, which augments both consumer surplus and tariff revenues, leading to welfare gain in the United States.

Trade liberalization and technological spillover in apple juice processing in China results in increased productivity and hence production. As a result, Chinese processors export more to the United States, affecting the profitability of U.S. processors. Consequently, the Chinese market share increases in the United States. Thus, U.S. apple juice processors face high competition and lose market share to Chinese processors. However, due to cheaper imports from China, the U.S. apple juice price decreases and U.S. consumer surplus increases.

Given the free trade agreements and negotiations such as the Doha Round agreement, U.S. apple juice processors need to increase their productivity. Similarly, U.S. apple growers should also enhance their productivity to increase apple production since apples are the single most important intermediate input in juice production. Also, U.S. apple juice processors should invest in advanced processing technologies to increase their competitiveness and hence profitability.

2.5 Supplementary Material: Math Derivations

Profit Function

The firm-level profit functions of U.S. and China apple juice concentrate processors are

$$\pi^{US} = p^{US}\left(Q^{UD}+Q^{CU}\right)q^{UD} - C^{UD}\left(q^{UD};\omega^{U}\right) - f^{U} \tag{24}$$

$$\begin{aligned}\pi^{C} = {} & \left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)q^{CU} + \tilde{p}^{CO}\tilde{q}^{CO} \\ & -C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right) - t^{U}q^{CU} - f^{C}\end{aligned} \tag{25}$$

First-Order Conditions

From the profit functions (24 and 25) we derive the first-order conditions with respect to q^{UD} and q^{CU} respectively.

United States

The reaction functions are defined by the first-order conditions:

$$\begin{aligned}\pi^{US}_{q^{UD}} = {} & q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}} \\ & +p^{US}\left(Q^{UD}+Q^{CU}\right)-\frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}}=0\end{aligned}$$

Under Cournot competition, $\dfrac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}=1$

Therefore the first-order condition for the United States AJC firm-level profit function with respect to q^{UD} is given by

$$\pi^{US}_{q^{UD}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}+p^{US}\left(Q^{UD}+Q^{CU}\right)-\frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}}=0 \tag{26}$$

China

The reaction functions are defined by the first order conditions:

$$\begin{aligned}\pi^{C}_{q^{CU}} = {} & q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}+\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right) \\ & -\frac{\partial C^{CU}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}-t^{U}=0\end{aligned}$$

Under Cournot competition, $\dfrac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}=1$

Therefore the first-order condition for the Chinese AJC firm-level profit function with respect to q^{CU} is given by

$$\pi^{C}_{CU} = q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} + \left(p^{US}-\tau^{U}\right) - \frac{\partial C^{CU}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}} - t^{U} = 0 \quad (27)$$

Zero-Profit Conditions

The zero-profit conditions are

$$\pi^{OUS} = p^{US}\left(Q^{UD}+Q^{CU}\right)q^{UD} - C^{UD}\left(q^{UD};\omega^{U}\right) - f^{U} = 0 \quad (28)$$

$$\begin{aligned}\pi^{OC} &= \left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right) - t^{U}q^{CU} - f^{C} \\ &= 0\end{aligned} \quad (29)$$

Second-Order Conditions

Since the demand functions are downward sloping and the cost function is convex, we know the reaction function constitutes a solution because the profit functions are globally concave implying the second-order conditions for a maximum are satisfied. Specifically, the second-order conditions are:

United States

To obtain the SOC $\pi^{US}_{q^{UD}q^{UD}}$, we differentiate equation (26) with respect to q^{UD},

$$\pi^{US}_{q^{UD}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} + p^{US}\left(Q^{UD}+Q^{CU}\right) - \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} = 0$$

$$\begin{aligned}\pi^{US}_{q^{UD}q^{UD}} &= q^{UD}\frac{\partial^2 p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}} \\ &\quad + \frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} + \frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}} \\ &\quad - \frac{\partial^2 C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}\partial q^{UD}} < 0\end{aligned}$$

Under Cournot competition $\dfrac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}} = 1$,

$$\pi^{US}_{q^{UD}q^{UD}} = q^{UD}\frac{\partial^2 p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)} + 2\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} - \frac{\partial^2 C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}\partial q^{UD}} < 0$$

To obtain the SOC $\pi^{US}_{q^{UD}q^{CU}}$, we differentiate equation (26) with respect to q^{CU},

$$\pi^{US}_{q^{UD}q^{CU}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$$
$$+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}} < 0$$

Under Cournot competition $\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}} = 1$,

$$\pi^{US}_{q^{UD}q^{CU}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} < 0$$

Redefining the aggregate quantities as firm-level quantities times the number of firms,

$$Q^{UD} = N^U q^{UD}$$
$$Q^C = Q^{CU} + \tilde{Q}^{CO} = N^C q^{CU} + N^C \tilde{q}^{CO} = N^C\left(q^{CU}+\tilde{q}^{CO}\right)$$
$$Q^{US} = Q^{UD} + Q^{CU} + Q^{USO}$$

Using the above definition, we rewrite the equation (26) as

$$\pi^{US}_{q^{UD}} = q^{UD}\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}$$
$$+p^{US}\left(N^U q^{UD}+N^C q^{CU}\right) - \frac{\partial C^{UD}\left(q^{UD};\omega^U\right)}{\partial q^{UD}} = 0$$

To obtain the SOC $\pi^{US}_{q^{UD}N^U}$, we differentiate equation (26) with respect to N^U,

$$\pi^{US}_{q^{UD}N^U} = q^{UD}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}$$
$$\underbrace{\frac{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial N^U q^{UD}}}_{=1}\underbrace{\frac{\partial N^U q^{UD}}{\partial N^U}}_{=q^{UD}}+\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\underbrace{\frac{\partial q^{UD}}{\partial N^U}}_{=0}$$
$$+\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\underbrace{\frac{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial N^U q^{UD}}}_{=1}\underbrace{\frac{\partial N^U q^{UD}}{\partial N^U}}_{=q^{UD}}$$

$$\pi^{US}_{q^{UD}N^U} = q^{UD}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}q^{UD}$$
$$+\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}q^{UD}$$

$$\pi^{US}_{q^{UD}N^U} = q^{UD}\left(q^{UD}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\right)$$
$$+q^{UD}\left(\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\right) < 0$$

To obtain the SOC $\pi^{US}_{q^{UD}N^C}$, we differentiate equation (26) with respect to N^C,

$$\pi^{US}_{q^{UD}N^C} = q^{UD}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}$$

$$\underbrace{\frac{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial N^Cq^{CU}}}_{=1}\underbrace{\frac{\partial N^Cq^{CU}}{\partial N^C}}_{=q^{CU}}+\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\underbrace{\frac{\partial q^{UD}}{\partial N^C}}_{=0}$$

$$+\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\underbrace{\frac{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial N^Cq^{CU}}}_{=1}\underbrace{\frac{\partial N^Cq^{CU}}{\partial N^C}}_{=q^{CU}}$$

$$\pi^{US}_{q^{UD}N^C}=q^{UD}\frac{\partial^2p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{CU}$$

$$+\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{CU}$$

$$\begin{aligned}\pi^{US}_{q^{UD}N^C} &= q^{CU}\left(q^{UD}\frac{\partial^2p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\right)\\ &\quad+q^{CU}\left(\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\right)<0\end{aligned}$$

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To obtain the SOC $\pi^C_{q^{CU}q^{UD}}$, we differentiate equation (27) with respect to q^{UD},

$$\pi^C_{q^{CU}q^{UD}}=q^{CU}\frac{\partial^2p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}\underbrace{\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}}_{=1}$$

$$+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\underbrace{\frac{\partial q^{CU}}{\partial q^{UD}}}_{=0}+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\underbrace{\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}}_{=1}<0,$$

$$\pi^C_{q^{CU}q^{UD}}=q^{CU}\frac{\partial^2p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}<0$$

$\pi^C_{q^{CU}q^{UD}}<0$ for stability condition (See Brander and Krugman,1983).

To obtain the SOC $\pi^C_{q^{CU}q^{CU}}$, we differentiate equation (27) with respect to q^{CU},

$$\pi^C_{q^{CU}q^{CU}}=q^{CU}\frac{\partial^2p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}\underbrace{\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}}_{=1}$$

$$+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\underbrace{\frac{\partial q^{CU}}{\partial q^{CU}}}_{=1}+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\underbrace{\frac{\partial q^{CU}}{\partial q^{CU}}}_{=1}$$

$$-\frac{\partial^2C^C\left(q^{CU}+\tilde{q}^{CO};\omega^C\right)}{\partial q^{CU}\partial q^{CU}}<0$$

$$\pi^C_{q^{CU}q^{CU}}=q^{CU}\frac{\partial^2p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}$$

$$+\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}-\frac{\partial^2 C^C\left(q^{CU}+\tilde{q}^{CO};\omega^C\right)}{\partial q^{CU}\partial q^{CU}}<0$$

$$\pi^C_{q^{CU}q^{CU}}=q^{CU}\frac{\partial^2 p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)\partial\left(Q^{UD}+Q^{CU}\right)}+2\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}$$
$$-\frac{\partial^2 C^C\left(q^{CU}+\tilde{q}^{CO};\omega^C\right)}{\partial q^{CU}\partial q^{CU}}<0$$

Redefining equation (27) by rewriting the aggregate quantities as firm-level quantities times the number of firms times,

$$\pi^C_{q^{CU}}=q^{CU}\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}+\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)$$
$$-\frac{\partial C^{CU}\left(q^{CU}+\tilde{q}^{CO};\omega^C\right)}{\partial q^{CU}}-t^U=0$$

To obtain the SOC $\pi^C_{q^{CU}N^U}$, we differentiate equation (27) with respect to N^U,

$$\pi^C_{q^{CU}N^U}=q^{CU}\frac{\partial^2 p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}$$
$$\underbrace{\frac{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}\right)}}_{=1}\underbrace{\frac{\partial\left(N^Uq^{UD}\right)}{\partial N^U}}_{=q^{UD}}+\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\underbrace{\frac{\partial q^{UD}}{\partial N^U}}_{=0}$$
$$+\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^u\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\underbrace{\frac{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}\right)}}_{=1}\underbrace{\frac{\partial\left(N^Uq^{UD}\right)}{\partial N^U}}_{=q^{UD}}$$

$$\pi^C_{q^{CU}N^U}=q^{CU}\frac{\partial^2 p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{UD}$$
$$+\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^u\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{UD}$$

Note: $\dfrac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^u\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}=\dfrac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}$

$$\pi^C_{q^{CU}N^U}=q^{CU}\frac{\partial^2 p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{UD}$$
$$+\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{UD}$$

$$\pi^C_{q^{CU}N^U}=q^{UD}\left(q^{CU}\frac{\partial^2 p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\right)$$
$$+q^{UD}\left(\frac{\partial p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\right)<0$$

To obtain the SOC $\pi^C_{q^{CU}N^C}$, we differentiate equation (27) with respect to N^C,

$$\pi^C_{q^{CU}N^C}=q^{CU}\frac{\partial^2 p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}$$

$$\underbrace{\frac{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^C q^{CU}\right)}}_{=1}\underbrace{\frac{\partial\left(N^C q^{CU}\right)}{\partial N^C}}_{=q^{su}}+\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\underbrace{\frac{\partial q^{CU}}{\partial N^C}}_{=0}$$

$$+\frac{\partial\left(p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)-\tau^u\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\underbrace{\frac{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^C q^{CU}\right)}}_{=1}\underbrace{\frac{\partial\left(N^C q^{CU}\right)}{\partial N^C}}_{=q^{CU}}$$

$$\pi^C_{q^{CU}N^C}=q^{CU}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}q^{CU}$$
$$+\frac{\partial\left(p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)-\tau^u\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}q^{CU}$$

Note: $\frac{\partial\left(p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)-\tau^u\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}=\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}$

$$\pi^C_{q^{CU}N^C}=q^{CU}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}q^{CU}$$
$$+\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}q^{CU}$$

$$\begin{aligned}\pi^C_{q^{CU}N^C} &= q^{CU}\left(q^{CU}\frac{\partial^2 p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\right)\\ &\quad +q^{CU}\left(\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\right)<0\end{aligned}$$

Differentiation of Zero Profit Conditions

Repeating the zero profit condition for the United States,

$$\pi^{OUS}=p^{US}\left(Q^{UD}+Q^{CU}\right)q^{UD}-C^{UD}\left(q^{UD};\omega^U\right)-f^U=0$$

$$\pi^{OUS}=p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)q^{UD}-C^{UD}\left(q^{UD};\omega^U\right)-f^U=0$$

The first-order condition of equation (28) with respect to q^{UD} is given by

$$\pi^{OUS}_{q^{UD}}=q^{UD}\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}\underbrace{\frac{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial N^U q^{UD}}}_{=1}\underbrace{\frac{\partial N^U q^{UD}}{\partial q^{UD}}}_{=N^U}$$

$$+p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)\underbrace{\frac{\partial q^{UD}}{\partial q^{UD}}}_{=1}-\frac{\partial C^{UD}\left(q^{UD};\omega^U\right)}{\partial q^{UD}}$$

$$\pi^{OUS}_{q^{UD}}=q^{UD}\frac{\partial p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)}{\partial\left(N^U q^{UD}+N^C q^{CU}\right)}N^U+p^{US}\left(N^U q^{UD}+N^C q^{CU}\right)$$

$$-\frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}}<0$$

$$\begin{aligned}\pi^{OUS}_{q^{UD}} &= N^{U}q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}+p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)\\ &\quad -\frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}}<0\end{aligned}$$

Since $\pi^{US}_{q^{UD}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}+p^{US}\left(Q^{UD}+Q^{CU}\right)$
$-\frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}}=0$, the above equation should be less than zero.

The first-order condition of equation (28) with respect to q^{CU} is given by

$$\begin{aligned}\pi^{OUS}_{q^{CU}} = q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}\underbrace{\frac{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial N^{C}q^{CU}}}_{=1}\underbrace{\frac{\partial N^{C}q^{CU}}{\partial q^{CU}}}_{=N^{C}}\\ +p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)\underbrace{\frac{\partial q^{UD}}{\partial q^{CU}}}_{=0}\end{aligned}$$

$$\pi^{OUS}_{q^{CU}} = q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}N^{C}<0$$

$$\pi^{OUS}_{q^{CU}} = N^{C}q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}<0$$

The first-order condition of equation (28) with respect to N^{U} is given by

$$\begin{aligned}\pi^{OUS}_{N^{U}} = q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}\underbrace{\frac{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial N^{U}q^{UD}}}_{=1}\underbrace{\frac{\partial N^{U}q^{UD}}{\partial N^{U}}}_{=q^{UD}}\\ +p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)\underbrace{\frac{\partial q^{UD}}{\partial N^{U}}}_{=0}\end{aligned}$$

$$\pi^{OUS}_{N^{U}} = q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}q^{UD}$$

$$\pi^{OUS}_{N^{U}} = \left(q^{UD}\right)^{2}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}<0$$

The first-order condition of equation (28) with respect to N^{C} is given by

$$\begin{aligned}\pi^{OUS}_{N^{C}} = q^{UD}\frac{\partial p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}\underbrace{\frac{\partial\left(N^{U}q^{UD}+N^{C}q^{CU}\right)}{\partial N^{C}q^{CU}}}_{=1}\underbrace{\frac{\partial N^{C}q^{CU}}{\partial N^{C}}}_{=q^{CU}}\\ +p^{US}\left(N^{U}q^{UD}+N^{C}q^{CU}\right)\underbrace{\frac{\partial q^{UD}}{\partial N^{C}}}_{=0}\end{aligned}$$

$$\pi^{OUS}_{N^C} = q^{UD} \frac{\partial p^{US}\left(N^U q^{UD} + N^C q^{CU}\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} q^{CU}$$

$$\pi^{OUS}_{N^C} = q^{UD} q^{CU} \frac{\partial p^{US}\left(N^U q^{UD} + N^C q^{CU}\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} < 0$$

Repeating the zero profit condition for China,

$$\pi^{OC} = \left(p^{US}\left(Q^{UD} + Q^{CU}\right) - \tau^U\right) q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - C^C\left(q^{CU} + \tilde{q}^{CO}; \omega^C\right) - t^U q^{CU} - f^C = 0$$

$$= \left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right) q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - C^C\left(q^{CU} + \tilde{q}^{CO}; \omega^C\right) - t^U q^{CU} - f^C = 0$$

The first-order condition of equation (29) with respect to q^{UD} is given by

$$\pi^{OC}_{q^{UD}} = q^{CU} \frac{\partial\left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} \underbrace{\frac{\partial\left(N^U q^{UD} + N^C q^{CU}\right)}{\partial N^U q^{UD}}}_{=1} \underbrace{\frac{\partial N^U q^{UD}}{\partial q^{UD}}}_{=N^U}$$

$$\pi^{OC}_{q^{UD}} = q^{CU} \frac{\partial\left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} N^U < 0$$

$$\pi^{OC}_{q^{UD}} = N^U q^{CU} \frac{\partial\left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} < 0$$

The first-order condition of equation (29) with respect to q^{CU} is given by

$$\pi^{OC}_{q^{CU}} = q^{CU} \frac{\partial\left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} \underbrace{\frac{\partial\left(N^U q^{UD} + N^C q^{CU}\right)}{\partial N^C q^{CU}}}_{=1} \underbrace{\frac{\partial N^C q^{CU}}{\partial q^{CU}}}_{=N^C} + \left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right) \underbrace{\frac{\partial q^{CU}}{\partial q^{CU}}}_{=1} - \frac{\partial C^C\left(q^{CU} + \tilde{q}^{CO}; \omega^C\right)}{\partial q^{CU}} - t^U$$

$$\pi^{OC}_{q^{CU}} = q^{CU} \frac{\partial\left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} N^C + \left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right) - \frac{\partial C^C\left(q^{CU} + \tilde{q}^{CO}; \omega^C\right)}{\partial q^{CU}} - t^U$$

$$\pi^{OC}_{q^{CU}} = N^C q^{CU} \frac{\partial\left(p^{US}\left(N^U q^{UD} + N^C q^{CU}\right) - \tau^U\right)}{\partial\left(N^U q^{UD} + N^C q^{CU}\right)} + \left(p^{US} - \tau^U\right) - \frac{\partial C^C\left(q^{CU} + \tilde{q}^{CO}; \omega^C\right)}{\partial q^{CU}} - t^U < 0$$

Since $\pi^C_{q^{CU}} = q^{CU}\dfrac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\dfrac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$
$+\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^U\right)-\dfrac{\partial C^{CU}\left(q^{CU}+\tilde{q}^{CO};\omega^C\right)}{\partial q^{CU}}-t^U=0$, the above equation is negative.

The first-order condition of equation (29) with respect to N^U is given by

$$\pi^{OC}_{N^U} = q^{CU}\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\underbrace{\frac{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial N^Uq^{UD}}}_{=1}\underbrace{\frac{\partial N^Uq^{UD}}{\partial N^U}}_{=q^{UD}}$$

$$\pi^{OC}_{N^U} = q^{CU}\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{UD}$$

$$\pi^{OC}_{N^U} = q^{UD}q^{CU}\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}<0$$

The first-order condition of equation (29) with respect to N^U is given by

$$\pi^{OC}_{N^C} = q^{CU}\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}\underbrace{\frac{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}{\partial N^Cq^{CU}}}_{=1}\underbrace{\frac{\partial N^Cq^{CU}}{\partial N^C}}_{=q^{CU}}$$

$$\pi^{OC}_{N^C} = q^{CU}\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}q^{CU}$$

$$\pi^{OC}_{N^C} = \left(q^{CU}\right)^2\frac{\partial\left(p^{US}\left(N^Uq^{UD}+N^Cq^{CU}\right)-\tau^U\right)}{\partial\left(N^Uq^{UD}+N^Cq^{CU}\right)}<0$$

The impact of a change in the tariff and Chinese productivity on the marginal change in profits is given by

$$\pi^{US}_{q^{UD}\tau^U}=0,\qquad \pi^{US}_{q^{UD}\omega^U}=-\frac{\partial^2C^{UD}\left(q^{UD};\omega^U\right)}{\partial q^{UD}\partial\omega^U}>0,\qquad \pi^{US}_{q^{UD}\omega^C}=0$$

$$\pi^{C}_{q^{CU}\tau^U}=-1<0,\qquad \pi^{C}_{q^{CU}\omega^U}=0,\qquad \pi^{C}_{q^{CU}\omega^C}=-\frac{\partial^2C^{C}\left(q^{CU}+q^{CO};\omega^C\right)}{\partial q^{CU}\partial\omega^C}>0$$

$$\pi^{OUS}_{\tau^U}=0,\qquad \pi^{OUS}_{\omega^U}=-\frac{\partial C^{UD}\left(q^{UD};\omega^U\right)}{\partial\omega^U}>0,\qquad \pi^{OUS}_{\omega^C}=0$$

$$\pi^{OC}_{\tau^U}=-q^{CU}<0,\qquad \pi^{OC}_{\omega^U}=0,\qquad \pi^{OC}_{\omega^C}=-\frac{\partial C^{C}\left(q^{CU}+q^{CU};\omega^C\right)}{\partial\omega^C}>0$$

Comparative Statics

Totally differentiating the FOCs yields a system of three equation, written in the form $Ax = d$ we get,

$$\begin{bmatrix} \pi^{US}_{q^{UD}q^{UD}} & \pi^{US}_{q^{UD}q^{CU}} & \pi^{US}_{q^{UD}N^{U}} & \pi^{US}_{q^{UD}N^{C}} \\ \pi^{C}_{q^{CU}q^{UD}} & \pi^{C}_{q^{CU}q^{CU}} & \pi^{C}_{q^{CU}N^{U}} & \pi^{C}_{q^{CU}N^{C}} \\ \pi^{OUS}_{q^{UD}} & \pi^{OUS}_{q^{CU}} & \pi^{OUS}_{N^{U}} & \pi^{OUS}_{N^{C}} \\ \pi^{OC}_{q^{UD}} & \pi^{OC}_{q^{CU}} & \pi^{OC}_{N^{U}} & \pi^{OC}_{N^{C}} \end{bmatrix} \begin{bmatrix} dq^{UD} \\ dq^{CU} \\ dN^{U} \\ dN^{C} \end{bmatrix} = - \begin{bmatrix} \pi^{US}_{q^{UD}\tau^{U}} d\tau^{U} + \pi^{US}_{q^{UD}\omega^{U}} d\omega^{U} + \pi^{US}_{q^{UD}\omega^{C}} d\omega^{C} \\ \pi^{C}_{q^{CU}\tau^{U}} d\tau^{U} + \pi^{C}_{q^{CU}\omega^{U}} d\omega^{U} + \pi^{C}_{q^{CU}\omega^{C}} d\omega^{C} \\ \pi^{OUS}_{\tau^{U}} d\tau^{U} + \pi^{OUS}_{\omega^{U}} d\omega^{U} + \pi^{OUS}_{\omega^{C}} d\omega^{C} \\ \pi^{OC}_{\tau^{U}} d\tau^{U} + \pi^{OC}_{\omega^{U}} d\omega^{U} + \pi^{OC}_{\omega^{C}} d\omega^{C} \end{bmatrix}$$

$$\begin{bmatrix} \pi^{US}_{q^{UD}q^{UD}} & \pi^{US}_{q^{UD}q^{CU}} & \pi^{US}_{q^{UD}N^{U}} & \pi^{US}_{q^{UD}N^{C}} \\ \pi^{C}_{q^{CU}q^{UD}} & \pi^{C}_{q^{CU}q^{CU}} & \pi^{C}_{q^{CU}N^{U}} & \pi^{C}_{q^{CU}N^{C}} \\ \pi^{OUS}_{q^{UD}} & \pi^{OUS}_{q^{CU}} & \pi^{OUS}_{N^{U}} & \pi^{OUS}_{N^{C}} \\ \pi^{OC}_{q^{UD}} & \pi^{OC}_{q^{CU}} & \pi^{OC}_{N^{U}} & \pi^{OC}_{N^{C}} \end{bmatrix} \begin{bmatrix} dq^{UD} \\ dq^{CU} \\ dN^{U} \\ dN^{C} \end{bmatrix} = - \begin{bmatrix} \pi^{US}_{q^{UD}\omega^{U}} d\omega^{U} \\ \pi^{C}_{q^{CU}\tau^{U}} d\tau^{U} + \pi^{C}_{q^{CU}\omega^{C}} d\omega^{C} \\ \pi^{OUS}_{\omega^{U}} d\omega^{U} \\ \pi^{OC}_{\tau^{U}} d\tau^{U} + \pi^{OC}_{\omega^{C}} d\omega^{C} \end{bmatrix}$$

The determinant of A is positive as shown by $|A| => 0$.

We analyze the effect of a change in τ^U and ω^C on q^{UD}, q^{CU}, N^U, and N^C by applying Cramer's rule.

Welfare Analysis of Tariff and Productivity Changes

Next, we analyze the welfare impacts of a reduction in the U.S. tariffs and Chinese productivity changes on the United States and China. For the United States, welfare is comprised of only consumer surplus and tariff revenues because producer surplus in zero due to the zero-profit condition:

$$W^{US}\left(Q^{US};\tau^{U},\omega^{U},\omega^{C}\right)=\left\{\int p^{US}\left(Q^{US}\right)dq^{US}-p^{US}\left(Q^{US}\right)Q^{US}\right\}+\tau^{U}Q^{CU}$$

The Chinese welfare is zero because of the zero-profit condition and zero consumer surplus since all production is exported.

United States Welfare Analysis of a Change in the U.S. Tariff

The welfare function for the United States consists of profits, consumer surplus, and tariff revenues. But under free entry and exit, profits are zero.

$$W^{US}\left(Q^{US};\tau^{U},\omega^{U},\omega^{C}\right)=\left\{\int p^{US}\left(Q^{US}\right)dq^{US}-p^{US}\left(Q^{US}\right)Q^{US}\right\}+\tau^{U}Q^{CU}$$

where consumer surplus, $CS=\int p^{US}\left(Q^{US}\right)dq^{US}-p^{US}\left(Q^{US}\right)Q^{US}$, and tariff revenue, $TR=\tau^{U}Q^{CU}$.

The change in consumer surplus with respect to a change in the U.S. tariff is:

$$\begin{aligned}\frac{dCS}{d\tau^{U}}&=p^{US}\left(Q^{US}\right)\frac{\partial Q^{US}}{\partial\tau^{U}}-Q^{US}\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial\tau^{U}}-p^{US}\frac{\partial Q^{US}}{\partial\tau^{U}}\\&=\left(p^{US}-\frac{\partial p^{US}}{\partial Q^{US}}Q^{US}-p^{US}\right)\frac{\partial Q^{US}}{\partial\tau^{U}}\\&=\left(-\frac{\partial p^{US}}{\partial Q^{US}}Q^{US}\right)\frac{\partial Q^{US}}{\partial\tau^{U}}.\end{aligned}$$

The change in tariff revenue with respect to a change in the U.S. tariff is:

$$\frac{dTR}{d\tau^{U}}=\tau^{U}\frac{\partial Q^{CU}}{\partial\tau^{U}}+Q^{CU}.$$

Therefore, we can express the total change in welfare as:

$$\begin{aligned}\frac{dW^{US}(\cdot)}{d\tau^{U}}&=\frac{dCS\left(Q^{US}\right)}{d\tau^{U}}+\frac{dR\left(Q^{US}\right)}{d\tau^{U}}\\&=\left(-\frac{\partial p^{US}}{\partial Q^{US}}Q^{US}\right)\frac{\partial Q^{US}}{\partial\tau^{U}}+\tau^{U}\frac{\partial Q^{CU}}{\partial\tau^{U}}+Q^{CU}\\&=\underbrace{-\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial\tau^{U}}Q^{US}}_{\text{CS}(-)}+\underbrace{\underbrace{\frac{\partial Q^{CU}}{\partial\tau^{U}}\tau^{U}}_{-}+\underbrace{Q^{CU}}_{+}}_{\text{TR}(?)}\end{aligned}$$

$$\frac{dW^{US}(\cdot)}{d\tau^U} = \underbrace{-\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial \tau^U}Q^{US}}_{\text{CS}(-)} + \underbrace{Q^{CU}\left(1+\frac{\partial Q^{CU}}{\partial \tau^U}\frac{\tau^U}{Q^{CU}}\right)}_{\text{TR}(?)}.$$

Tariff revenue depends on the elasticity of import demand curve, and consequently, the welfare could be positive or negative.

Chinese Productivity Shock (Change in ω^C)

United States Welfare Analysis of an increase in Chinese Productivity

The welfare function for the United States consists of profits, consumer surplus, and tariff revenues. But under free entry and exit, profits are zero.

$$W^{US}\left(Q^{US};\tau^U,\omega^U,\omega^C\right) = \left\{\int p^{US}\left(Q^{US}\right)dq^{US} - p^{US}\left(Q^{US}\right)Q^{US}\right\} + \tau^U Q^{CU}$$

where consumer surplus, $CS = \int p^{US}\left(Q^{US}\right)dq^{US} - p^{US}\left(Q^{US}\right)Q^{US}$, and tariff revenue, $TR = \tau^U Q^{CU}$.

The change in consumer surplus with respect to a change in Chinese productivity is

$$\begin{aligned}\frac{dCS(\cdot)}{d\omega^C} &= p^{US}\left(Q^{US}\right)\frac{\partial Q^{US}}{\partial \omega^C} - Q^{US}\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial \omega^C} - p^{US}\frac{\partial Q^{US}}{\partial \omega^C} \\ &= \left(-\frac{\partial p^{US}}{\partial Q^{US}}Q^{US}\right)\frac{\partial Q^{US}}{\partial \omega^C}.\end{aligned}$$

The change in tariff revenue with respect to a change in Chinese productivity is

$$\begin{aligned}\frac{dTR(\cdot)}{d\omega^C} &= \frac{d\left(Q^{CU}\tau^U\right)}{d\omega^C} \\ \frac{dTR(\cdot)}{d\omega^C} &= \tau^U\frac{\partial Q^{CU}}{\partial \omega^C}\end{aligned}$$

Therefore, we can express the total change in welfare as:

$$\begin{aligned}\frac{dW^{US}(\cdot)}{d\omega^C} &= \frac{dCS\left(Q^{US}\right)}{d\omega^C} + \frac{dR\left(Q^{US}\right)}{d\omega^C} \\ &= \underbrace{-\frac{\partial p^{US}}{\partial Q^{US}}\frac{\partial Q^{US}}{\partial \omega^C}Q^{US}}_{\text{CS}(+)} + \underbrace{\tau^U\frac{\partial Q^{CU}}{\partial \omega^C}}_{\text{TR}(+)}.\end{aligned}$$

The above results show that the welfare would be positive.

Empirical Model and Analysis

Empirical Model

Supply Relations

United States Domestic Supply Relation

$$\pi^{US}_{q^{UD}} = q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}} + p^{US}\left(Q^{UD}+Q^{CU}\right) - \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} = 0$$

$$q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}} + p^{US}\left(Q^{UD}+Q^{CU}\right) - \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} = 0$$

$$p^{US}\left(Q^{UD}+Q^{CU}\right) = \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} - q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}$$

$$p^{US}\left(Q^{UD}+Q^{CU}\right) = \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} - q^{UD}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} \frac{\left(Q^{UD}+Q^{CU}\right)}{\left(Q^{UD}+Q^{CU}\right)}\frac{p^{US}\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}$$

$$p^{US}\left(Q^{UD}+Q^{CU}\right) = \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} - \frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)} \frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}\frac{q^{UD}}{\left(Q^{UD}+Q^{CU}\right)}p^{US}\left(Q^{UD}+Q^{CU}\right)$$

$$p^{US}\left(Q^{UD}+Q^{CU}\right) = \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} + \frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}\frac{q^{UD}}{\left(Q^{UD}+Q^{CU}\right)} \left(-\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}\right)p^{US}\left(Q^{UD}+Q^{CU}\right)$$

$\psi^{US} = \frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{UD}}\frac{q^{UD}}{\left(Q^{UD}+Q^{CU}\right)}$ is the conjectural elasticity of a U.S. domestic firm.

$\xi^{US} = -\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}$ is the demand flexibility in the U.S. market.

$$p^{US}\left(Q^{UD}+Q^{CU}\right) = \frac{\partial C^{UD}\left(q^{UD};\omega^{U}\right)}{\partial q^{UD}} + \psi^{US}\xi^{US}p^{US}\left(Q^{UD}+Q^{CU}\right)$$

China's Export Supply Relation

$$\pi^{C}_{q^{CU}} = q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$$

$$+\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)-\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}-t^{U}=0$$

$$q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$$
$$+\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)-\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}-t^{U}=0$$

$$\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)=\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}$$
$$+t^{U}-q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$$

$$\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)=\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}+t^{U}$$
$$-q^{CU}\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\left(Q^{UD}+Q^{CU}\right)}{\left(Q^{UD}+Q^{CU}\right)}\frac{p^{US}\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$$

$$\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)=\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}+t^{U}-\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}$$
$$\frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}\frac{q^{CU}}{\left(Q^{UD}+Q^{CU}\right)}p^{US}\left(Q^{UD}+Q^{CU}\right)$$

$$\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)=\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}+t^{U}+\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}$$
$$\frac{q^{CU}}{\left(Q^{UD}+Q^{CU}\right)}\left(-\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}\frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}\right)p^{US}\left(Q^{UD}+Q^{CU}\right)$$

$\psi^{CU}=\frac{\partial\left(Q^{UD}+Q^{CU}\right)}{\partial q^{CU}}\frac{q^{CU}}{\left(Q^{UD}+Q^{CU}\right)}$ is the conjectural elasticity of Chinese firm exporting to the United States.

$$\left(p^{US}\left(Q^{UD}+Q^{CU}\right)-\tau^{U}\right)=\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}+t^{U}$$
$$+\psi^{CU}\xi^{US}p^{US}\left(Q^{UD}+Q^{CU}\right)$$

$$p^{US}\left(Q^{UD}+Q^{CU}\right)=\frac{\partial C^{C}\left(q^{CU}+\tilde{q}^{CO};\omega^{C}\right)}{\partial q^{CU}}+t^{U}+\psi^{CU}\xi^{US}p^{US}\left(Q^{UD}+Q^{CU}\right)+\tau^{U}$$

Demand Functions

$p^{US}\left(Q^{UD}+Q^{CU}\right)=\mu_0^{US}+\mu_1^{US}\left(Q^{UD}+Q^{CU}\right)+\mu^{US}\mathbf{Z}^{US}$

Therefore the U.S. flexibility can be written as

$\xi^{US}=-\mu_1^{US}\frac{\left(Q^{UD}+Q^{CU}\right)}{p^{US}\left(Q^{UD}+Q^{CU}\right)}$ where $\mu_1^{US}=-\frac{\partial p^{US}\left(Q^{UD}+Q^{CU}\right)}{\partial\left(Q^{UD}+Q^{CU}\right)}$, the slope of the U.S. demand function.

Specific Functional Forms for Cost Functions and Supply Relations

Cost functions The marginal cost functions for the United States is

$$mc^{UD} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD}$$

The marginal cost functions for China is

$$mc^{C} = \lambda_0^{C} + \lambda_1^{C} \left(q^{CU} + \tilde{q}^{CO}\right)$$

With specific marginal cost functions, the U.S. domestic supply relation is

$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD} + \psi^{US} \mu_1^{US} \left(N^U q^{UD} + N^C q^{CU}\right)$, and

the Chinese export supply relation is

$p^{US} = \lambda_0^{CU} + \lambda_1^{CU} \left(q^{CU} + \tilde{q}^{CO}\right) + t^U + \psi^{CU} \mu_1^{CU} \left(N^U q^{UD} + N^C q^{CU}\right) + \tau^U.$

Drift Variables To account for structural changes in the U.S. domestic supply and Chinese exports to the United States, we incorporate drift variables into the supply relations.

$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD} + \psi^{US} \mu_1^{US} \left(N^U q^{UD} + N^C q^{CU}\right)$

$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD} + \left(\zeta_1 + \zeta_2 Drift\right) \mu_1^{US} \left(N^U q^{UD} + N^C q^{CU}\right)$

where $\psi^{US} = \zeta_1 + \zeta_2 Drift$

$\zeta_1 = \dfrac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{UD}} \dfrac{q^{UD}}{\left(N^U q^{UD} + N^C q^{CU}\right)}$

$\zeta_2 = \dfrac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{UD}} \dfrac{q^{UD}}{\left(N^U q^{UD} + N^C q^{CU}\right)} Drift$

$Drift = \dfrac{t - t_0}{t_f - t_0} I_{(t_0, t_f]}(t) + I_{(t_f, t_N]}$

The U.S. domestic supply relation is given by

$$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD} + \boldsymbol{\lambda}^{UD} \mathbf{x}^{UD} + \left(\zeta_1 + \zeta_2 Drift\right) \mu_1^{US} \left(Q^{UD} + Q^{CU}\right)$$

Similarly the Chinese export relation to the United States is given by

$$p^{US} = \lambda_0^{C} + \lambda_1^{C} \left(q^{CU} + \tilde{q}^{CO}\right) + \boldsymbol{\lambda}^{C} \mathbf{x}^{C} + t^U Q^{CU} + \left(\varphi_1 + \varphi_2 Drift\right) \mu_1^{US} \left(Q^{UD} + Q^{CU}\right) + \tau^U Q^{CU}$$

The conjectural elasticity ψ^{CU} is rewritten as $\psi^{CU} = \left(\varphi_1 + \varphi_2 Drift\right)$,

where $\varphi_1 = \dfrac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{CU}} \dfrac{q^{CU}}{\left(Q^{UD} + Q^{CU}\right)}$, $\varphi_2 = \dfrac{\partial \left(Q^{UD} + Q^{CU}\right)}{\partial q^{CU}} \dfrac{q^{CU}}{\left(Q^{UD} + Q^{CU}\right)} Drift$,

and $Drift = \dfrac{t - t_0}{t_f - t_0} I_{(t_0, t_f]}(t) + I_{(t_f, t_N]}$.

System of Equations for Econometric Estimation

The final system of equations is p^{US}, Q^{UD}, and Q^{CU}

U.S. Domestic Supply

$$p^{US} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD} + \boldsymbol{\lambda}^{UD}\mathbf{x}^{UD} + (\zeta_1 + \zeta_2 Drift)\,\mu_1^{US}\left(Q^{UD} + Q^{CU}\right)$$

Chinese Supply to the United States

$$p^{US} = \lambda_0^{C} + \lambda_1^{C}\left(q^{CU} + \tilde{q}^{CO}\right) + \boldsymbol{\lambda}^{C}\mathbf{x}^{C} + t^{U} + (\varphi_1 + \varphi_2 Drift)\,\mu_1^{US}\left(Q^{UD} + Q^{CU}\right) + \tau^{U}$$

U.S. Demand

$$p^{US} = \mu_0^{US} + \mu_1^{US}\left(Q^{UD} + Q^{CU}\right) + \boldsymbol{\mu}^{US}\mathbf{Z}^{US}$$

Simulation

In this section, we quantify the effect of free trade and changes in productivity on prices, quantities and welfare.

Supply relations

The firm-level U.S. and Chinese supply relations are

$$p^{US}\left(Q^{UD} + Q^{CU}\right) = \frac{\partial C^{UD}\left(q^{UD}; \omega^{U}\right)}{\partial q^{UD}} + \psi^{US}\xi^{US}p^{US}\left(Q^{UD} + Q^{CU}\right)$$

$$p^{US}\left(Q^{UD} + Q^{CU}\right) = \frac{\partial C^{C}\left(q^{CU} + \tilde{q}^{CO}; \omega^{C}\right)}{\partial q^{CU}} + t^{U} + \psi^{CU}\xi^{US}p^{US}\left(Q^{UD} + Q^{CU}\right) + \tau^{U}$$

Substitute the firm-level marginal cost functions into the above equations,

$$p^{US}\left(Q^{UD} + Q^{CU}\right) = \lambda_0^{UD} + \lambda_1^{UD}q^{UD} + \psi^{US}\xi^{US}p^{US}\left(Q^{UD} + Q^{CU}\right)$$

$$p^{US}\left(Q^{UD} + Q^{CU}\right) = \lambda_0^{C} + \lambda_1^{C}\left(q^{CU} + q^{CO}\right) + t^{U} + \psi^{CU}\xi^{US}p^{US}\left(Q^{UD} + Q^{CU}\right) + \tau^{U}$$

Derivation of Supply Parameters

United States:

$$p^{US}\left(Q^{UD} + Q^{CU}\right) = \lambda_0^{UD} + \lambda_1^{UD}N^{U}q^{UD} + \psi^{US}\xi^{US}p^{US}\left(Q^{UD} + Q^{CU}\right)$$

Multiply both sides by N^{U},

$$p^{US}N^{U} = \left(\lambda_0^{UD} + \lambda_1^{UD}Q^{UD}\right)N^{U} + \psi^{US}\xi^{US}p^{US}N^{U}$$

$$p^{US}N^{U} = \left(\lambda_0^{UD} + \lambda_1^{UD}Q^{UD}\right)N^{U} + \psi^{US}\mu_1^{US}\left(Q^{UD} + Q^{CU}\right)N^{U}$$

$$p^{US}N^{U} = \left(\lambda_0^{UD} + \lambda_1^{UD}N^{U}q^{UD}\right)N^{U} + \psi^{US}\mu_1^{US}\left(N^{U}q^{UD} + N^{C}q^{CU}\right)N^{U}$$

We know N^U, $q^{UD}N^U$, p^{US}, ψ^{US}, μ_1^{US}, ε_u^s

Getting λ_1^{UD}

$\varepsilon_u^s = \frac{\partial p^{US}}{\partial q^{UD}N^U}\frac{q^{UD}N^U}{p^{US}}$

$p^{US}N^U = \lambda_0^{UD}N^U + \lambda_1^{UD}\left(N^U q^{UD}\right)N^U + \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^C q^{CU}\right)N^U$

$p^{US} = \lambda_0^{UD} + \lambda_1^{UD}N^U q^{UD} + \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^C q^{CU}\right)$

$\frac{\partial p^{US}}{\partial q^{UD}N^U} = \lambda_1^{UD} + \psi^{US}\mu_1^{US}$

$\varepsilon_u^s = \left(\lambda_1^{UD} + \psi^{US}\mu_1^{US}\right)\frac{q^{UD}N^U}{p^{US}} = \left(\lambda_1^{UD}N^U + N^U\psi^{US}\mu_1^{US}\right)\frac{q^{UD}}{p^{US}}$

$\varepsilon_u^s\frac{p^{US}}{q^{UD}} = \lambda_1^{UD}N^U + N^U\psi^{US}\mu_1^{US}$

$$\lambda_1^{UD} = \varepsilon_u^s\frac{p^{US}}{q^{UD}N^U} - \psi^{US}\mu_1^{US}$$

Getting λ_0^{UD}

$p^{US}N^U = \lambda_0^{UD}N^U + \lambda_1^{UD}\left(N^U q^{UD}\right)N^U + \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^C q^{CU}\right)N^U$

$\lambda_0^{UD}N^U = p^{US}N^U - \lambda_1^{UD}\left(N^U q^{UD}\right)N^U - \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^C q^{CU}\right)N^U$

$\lambda_0^{UD} = p^{US} - \lambda_1^{UD}\left(N^U q^{UD}\right) - \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^C q^{CU}\right)$

$$\lambda_0^{UD} = p^{US} - \lambda_1^{UD}\left(N^U q^{UD}\right) - \psi^{US}\mu_1^{US}\left(N^U q^{UD} + N^C q^{CU}\right)$$

Chinese Supply to United States:

$p^{US}\left(Q^{UD} + Q^{CU}\right) = \lambda_0^{CU} + \lambda_1^{CU}\left(Q^{CU} + \tilde{Q}^{CO}\right) + t^U + \psi^{CU}\xi^{US}p^{US}\left(Q^{UD} + Q^{CU}\right) + \tau^U$

$p^{US}N^C = \left(\lambda_0^{CU} + \lambda_1^{CU}\left(Q^{CU} + \tilde{Q}^{CO}\right)\right)N^C + N^C t^U + \psi^{CU}\xi^{US}p^{US}N^C + N^C\tau^U$

$p^{US}N^C = \left(\lambda_0^{CU} + \lambda_1^{CU}\left(Q^{CU} + \tilde{Q}^{CO}\right)\right)N^C + N^C t^U + \psi^{CU}\mu_1^{US}\left(Q^{UD} + Q^{CU}\right)N^C + N^C\tau^U$

$p^{US}N^C = \left(\lambda_0^{CU} + \lambda_1^{CU}\left(N^C q^{CU} + N^C\tilde{q}^{CO}\right)\right)N^C + N^C t^U + \psi^{CU}\mu_1^{US}\left(N^C q^{CU} + N^U q^{UD}\right)N^C + N^C\tau^U$

We know N^C, $q^{CU}N^C$, $N^U q^{UD}$, p^{US}, μ_1^{US}, ψ^{CU}, ε_s^{CU}, t^U ,τ^U

Getting λ_1^{CU}

$\varepsilon_s^{CU} = \frac{\partial p^{US}}{\partial q^{CU}N^C}\frac{q^{CU}N^C}{p^{US}}$(Supply elasticity, China to U.S.)

$$p^{US} = \lambda_0^{CU} + \lambda_1^{CU} \frac{\left(N^C q^{CU} + N^U q^{UD}\right) N^C}{N^C} + t^U + \psi^{CU} \mu_1^{US} \left(N^C q^{CU} + N^U q^{UD}\right) + \tau^U$$
$$\frac{\partial p^{US}}{\partial q^{CU} N^C} = \lambda_1^{CU} + \psi^{CU} \mu_1^{US}$$
$$\varepsilon_s^{CU} = \left(\lambda_1^{CU} + \psi^{CU} \mu_1^{US}\right) \frac{q^{CU} N^C}{p^{US}} = \left(\lambda_1^{CU} N^C + N^C \psi^{CU} \mu_1^{US}\right) \frac{q^{CU}}{p^{US}}$$
$$\varepsilon_s^{CU} \frac{p^{US}}{q^{CU}} = \lambda_1^{CU} N^C + N^C \psi^{CU} \mu_1^{US}$$
$$\lambda_1^{CU} = \varepsilon_s^{CU} \frac{p^{US}}{q^{CU} N^C} - \psi^{CU} \mu_1^{US}$$

Once we know λ_1^{CU}, solve for λ_0^{CU}

$$p^{US} = \lambda_0^{CU} + \lambda_1^{CU} \left(N^C q^{CU} + N^C \tilde{q}^{CO}\right) + t^U + \psi^{CU} \mu_1^{US} \left(N^C q^{CU} + N^U q^{UD}\right) + \tau^U$$

$$\lambda_0^{CU} = p^{US} - \lambda_1^{CU} \left(N^C q^{CU} + N^C \tilde{q}^{CO}\right) - t^U - \psi^{CU} \mu_1^{US} \left(N^C q^{CU} + N^U q^{UD}\right) - \tau^U$$

Cost Functions

The total cost function for a U.S. processor is derived as

$$mc^{UD} = \frac{\partial C^{UD}}{\partial q^{UD}} = \lambda_0^{UD} + \lambda_1^{UD} q^{UD}$$
$$tc^{UD} = \int \left(\lambda_0^{UD} + \lambda_1^{UD} q^{UD}\right) dq^{UD}$$
$$= \lambda_0^{UD} q^{UD} + \frac{\lambda_1^{UD}}{2} \left(q^{UD}\right)^2 + \tilde{c}$$
$$tc^{UD} = \lambda_0^{UD} q^{UD} + \frac{\lambda_1^{UD}}{2} \left(q^{UD}\right)^2 + f^U$$

For industry-level total cost, we incorporate the number of firms, N^U into the above equation,

$$TC^{UD} = \lambda_0^{UD} N^U q^{UD} + \frac{\lambda_1^{UD}}{2} \left(N^U q^{UD}\right)^2 + N^U f^U$$

The total cost function for a Chinese firm is derived as

$$mc^C = \frac{\partial C^C}{\partial q^{CU}} = \lambda_0^C + \lambda_1^C \left(q^{CU} + q^{CO}\right)$$
$$tc^C = \int \left(\lambda_0^C + \lambda_1^C \left(q^{CU} + q^{CO}\right)\right) dq^{CU}$$
$$= \lambda_0^C q^{CU} + \frac{\lambda_1^C}{2} \left(q^{CU}\right)^2 + \lambda_1^C q^{CU} q^{CO} + \tilde{c}$$
$$= \lambda_0^C q^{CU} + \frac{\lambda_1^C}{2} \left(q^{CU}\right)^2 + \lambda_1^C q^{CU} q^{CO} + \frac{\lambda_1^C}{2} \left(q^{CO}\right)^2 + \tilde{c}$$

The firm-level total cost is given by

$$tc^{C} = \lambda_0^C q^{CU} + \frac{\lambda_1^C}{2}\left(q^{CU}\right)^2 + \lambda_1^C q^{CU} q^{CO} + \frac{\lambda_1^C}{2}\left(q^{CO}\right)^2 + f^C$$

For industry-level total cost, we incorporate the number of firms, N^C into the above equation,

$$TC^{C} = \lambda_0^C N^C q^{CU} + \frac{\lambda_1^C}{2}\left(N^C q^{CU}\right)^2 + \left(N^C q^{CU}\right)\left(N^C \tilde{q}^{CO}\right) + N^C f^C$$

Incorporating the above two total cost functions into zero-profit conditions

ZPC for U.S. Domestic AJC firm is

$$\pi^{OUS} = p^{US} q^{UD} - \lambda_0^{UD} q^{UD} - \frac{\lambda_1^{UD}}{2}\left(q^{UD}\right)^2 - f^U = 0$$

ZPC for Chinese AJC firm is

$$\begin{aligned}\pi^{OC} \quad &= \quad \left(p^{US} - \tau^U\right) q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - \lambda_0^C q^{CU} - \frac{\lambda_1^C}{2}\left(q^{CU}\right)^2 \\ &\quad -\lambda_1^C q^{CU} q^{CO} - \frac{\lambda_1^C}{2}\left(q^{CO}\right)^2 - f^C.\end{aligned}$$

System of Equations for Simulation

U.S. Supply Relation:

$$p^{US}\left(Q^{UD} + Q^{CU}\right) = \lambda_0^{UD} + \lambda_1^{UD} q^{UD} + \psi^{US}\xi^{US} p^{US}\left(Q^{UD} + Q^{CU}\right)$$

Chinese Export Relation:

$$p^{US} = \lambda_0^{CU} + \lambda_1^{CU}\left(q^{CU} + \tilde{q}^{CO}\right) + t^U + \psi^{CU}\mu_1^{US}\left(N^C q^{CU} + N^U q^{UD}\right) + \tau^U$$

U.S. Demand Equation:

$$p^{US} = \mu_0^{US} + \mu_1^{US}\left(Q^{UD} + Q^{CU}\right) + \boldsymbol{\mu}^{US}\mathbf{Z}^{US}$$

ZPC for U.S. Domestic AJC firm:

$$\pi^{OUS} = p^{US} q^{UD} - \lambda_0^{UD} q^{UD} - \frac{\lambda_1^{UD}}{2}\left(q^{UD}\right)^2 - f^U = 0$$

ZPC for Chinese AJC firm:

$$\begin{aligned}\pi^{OC} \quad &= \quad \left(p^{US} - \tau^U\right) q^{CU} - \tilde{p}^{CO}\tilde{q}^{CO} - \lambda_0^C q^{CU} - \frac{\lambda_1^C}{2}\left(q^{CU}\right)^2 \\ &\quad -\lambda_1^C q^{CU} q^{CO} - \frac{\lambda_1^C}{2}\left(q^{CO}\right)^2 - f^C.\end{aligned}$$

CHAPTER 3

ANALYSIS OF TRADE LIBERALIZATION AND PRODUCTIVITY CHANGES IN THE ORANGE JUICE MARKET

3.1 Introduction

Since the 1980s, world orange juice production has steadily increased at an average annual growth rate of 2.29% (FAOSTAT, 2014). Increased productivity, improvements in transportation, and enhanced packaging have resulted in lower cost and better quality orange juice. These supply factor changes coupled with rising income and a shift in consumers' preference toward healthy food have led to higher consumption which increased at an annual growth rate of 2.76% (FAOSTAT, 2014). The leading orange juice producers are the United States and Brazil, accounting for 88% of total world orange juice production over the period 2007-2011 (USDA-FAS, 2014). In the United States, Florida accounts for about 70% of total orange production with 95% of oranges being processed for juice (USDA-NASS, 2014). More than 90% of the Florida-processed orange juice is sold domestically (USDA-FAS, 2014). In Brazil, the state of São Paulo is the largest producer of oranges and orange juice, and exports 99% of its juice production (Mendes, 2011), with 77% exported to the United States and the European Union (EU) during 2007-2011 (FAOSTAT, 2014). In the United States, 90% of the orange juice market is controlled by Florida and São Paulo processors. During 2007-2011, the United States imported 16% of its total orange juice consumption, with 51% of the imports coming from São Paulo (USDA-FAS, 2014).

Orange juice production is highly concentrated in both Florida and São Paulo with few processors: 17 in Florida and 3 in São Paulo (USITC, 2014). Past studies have shown that the concentration of firms in this industry has lead to oligopolistic competition, and consequently processors exert control over sales and prices. Wang, Xiang, and Reardon (2006) find that Florida processors exert market power in the U.S. market. Luckstead, Devadoss, and Mittelhammer (2014a) show that Florida and São Paulo processors exert market power in the U.S.

and European orange juice markets. These studies conclude that the degree of market power is high, as these processors control more than 90% of total world orange juice sales.

The leading consumers of orange juice, both in terms of total quantity and on a per-capita basis, are the United States followed by the European Union. Since domestic orange juice production is very limited, the European Union meets its consumption through imports, accounting for 58% of the total world orange juice imports during 2007-2011 (FAOSTAT, 2014). In the United States, even though Florida produces a large volume of orange juice, exports are negligible due to high domestic consumption (U.S. Census Bureau, 2014). Thus, the European Union relies largely on São Paulo processors for its orange juice imports.

Both the United States and the European Union impose tariffs on orange juice imports. Florida processors were buffered from international competition with an import tariff of $0.3501 per single-strength equivalent (SSE) gallon under the General Agreement on Tariffs and Trade starting in 1947 (Zekri, 2003). This tariff remained unchanged until the Uruguay Round agreement in 1994, which stipulated that the tariff be reduced by 15% to $0.2971 per SSE gallon by 2000. The European Union also imposed an ad valorem tariff of 19% until 1994 on orange juice imports as a part of the agricultural import restrictions imposed on non-colonial countries. This tariff was reduced to 15.20% by 2000 under the Uruguay Round agreement (Spreen, Brewster, and Brown, 2003).

Spreen, Brewster, and Brown (2003) construct a spatial equilibrium model for the world processed orange juice market under perfect competition to estimate the impact of the U.S. import tariff elimination on U.S. orange juice production, producer prices, and imports. They find that U.S. import tariff elimination reduces Florida processors' price by $0.22 per SSE gallon. Wang, Xiang, and Reardon (2006) utilize the new empirical industrial organization (NEIO) to estimate the impact of weather shocks on the market power of Florida processors and conclude that processors become more competitive as a result of supply shocks. Luckstead, Devadoss, and Mittelhammer (2014a) use new trade theory and NEIO to analyze and estimate the impacts of U.S. and EU tariff reduction on Florida and São Paulo orange juice processors in the U.S. and EU orange juice markets under oligopolistic competition.

With higher concentration, a smaller number of firms, and larger market shares, trade policies and productivity will affect the market structure and ultimately welfare, which calls for endogenously determining the number of firms in the orange juice markets. This is critical because changes in trade policy and productivity will impact whether marginal orange juice processors continue to operate or exit the market. This study advances the literature by considering the effect of free trade and technological progress on the number of Florida and São Paulo firms operating and U.S., EU and São Paulo welfare.

The objectives of this study are to 1) construct a strategic trade model with free entry and exit to analyze the oligopolistic competition of Florida and São Paulo orange juice processors, 2) theoretically analyze the effect of a change in the U.S. and EU tariffs and São Paulo productivity on U.S., EU, and Brazilian orange juice markets, and 3) quantify through simulation analysis the effect of free trade and productivity changes on the number of orange juice firms, prices, supply, demand, trade, and welfare in the United States, Brazil, and the European Union.

3.2 Theoretical Model and Analysis

Since the 1970s, new trade theory has shown that countries with similar resource endowments and technology engage in trade because of increasing returns to scale, imperfect competition, and differentiated goods. Krugman (1979) found that returns to scale alter the pattern of comparative advantage. Later models incorporate imperfect competition (oligopolistic competition and monopolistic competition) into trade models to analyze strategic trade policy, reciprocal dumping, intra-industry trade, etc. (Brander, 1981; Brander and Krugman, 1983; Spencer and Brander, 1983; Brander and Spencer, 1985). New trade theory has since evolved to allow for productivity differences among firms and endogenous operating decisions to reflect the real-world phenomena that a small number of highly productive firms engage in trade (Melitz, 2003). The Melitz model shows that trade barriers, such as tariffs, shelter less productive firms and the removal of such policies leads to gains in welfare. Melitz and Ottaviano (2008) extend this analysis by incorporating a non-constant elasticity of substitution preference structure, which allows endogeneity in mark up and market power.

In agricultural markets, few studies have analyzed oligopolistic competition under trade policies.[1] This study extends Spreen, Brewster, and Brown (2003) and Luckstead, Devadoss, and Mittelhammer (2014a) by explicitly allowing the market structure to change endogenously through free entry and exit of firms as a result of changes in trade policy and productivity of Florida and São Paulo processors. Free entry and exit of firms is modeled using the zero profit condition in the model (Bowen, Hollander, and Viaene, 2012).

To reflect the market structure described in the introduction, we construct a strategic trade model based on new trade theory for the U.S., EU, and São Paulo orange juice markets. Production is concentrated in Florida and São Paulo, whereas consumption is spread throughout the United States and European Union. Orange juice produced by Florida processors is consumed domestically, whereas São Paulo processors export orange juice to both U.S. and EU markets. For São Paulo, we assume no domestic consumption since 99% of their processed oranges are exported (Mendes, 2011). São Paulo has a comparative advantage in orange juice production over Florida due to conducive weather, lower input prices, and labor costs. The United States imposes a specific tariff on orange juice imports to protect domestic processors. The European Union imposes an ad valorem tariff on orange juice imports from São Paulo. The Florida firm-level profit function is given by

$$\pi^f = p^u \left(Q^f + Q^{su}\right) q^f - C^f \left(q^f ; \theta^f\right) - f^f, \tag{30}$$

where p^u is the price of orange juice in the U.S. market, $p^u \left(Q^f + Q^{su}\right)$ is the U.S. inverse demand function, Q^f is the quantity of orange juice sold by Florida processors in the United States, Q^{su} is the quantity of orange juice sold by São Paulo processors in the United States, q^f

[1] Braga and Silber (1991) estimate the impact of U.S.anti-dumping duties against the Brazilian frozen concentrated orange juice on market power and welfare in the world orange juice market. Perloff and Ward (2003) analyze the welfare, market power and price effects of differentiated products in canned juices. Luckstead, Devadoss, and Mittelhammer (2014b) apply strategic trade theory and new empirical industrial organization to examine the degree of market power in U.S. and ASEAN apple markets.

is the firm-level output, $C^f\left(q^f;\theta^f\right)$ is the variable cost function, f^f is the fixed cost, and θ^f is the productivity parameter associated with each processor.

The São Paulo firm-level profit function is given by

$$\pi^s = \left(p^u\left(Q^f + Q^{su}\right) - \tau^u\right)q^{su} + \frac{p^e\left(Q^{se}\right)}{(1+\tau^e)}q^{se} - C^s\left(q^{su} + q^{se};\theta^s\right) - t^u q^{su} - t^e q^{se} - f^s, \quad (31)$$

where q^{su} is the firm-level output sold in the United States, p^e is the price of orange juice in the European Union, $p^e\left(Q^{se}\right)$ is the EU inverse demand function, Q^{se} is the quantity of orange juice sold in the European Union by São Paulo processors, q^{se} is the firm-level output sold in the European Union, $C^s\left(q^{su} + q^{se};\theta^s\right)$ is the variable cost function, f^s is the fixed cost, θ^s is the firm-level productivity parameter of São Paulo processors, τ^u is the specific tariff imposed by the United States, τ^e is the ad valorem tariff imposed by the European Union, t^u is the transport cost of shipments from São Paulo to the United States, and t^e is the transport cost of exports from São Paulo to the European Union.

We differentiate the profit functions (30) and (31) with respect to q^f, q^{su}, and q^{se} to obtain the first-order conditions, which are rearranged to obtain the reaction functions:

$$\begin{aligned}
\pi^f_{q^f} &= p^u - \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f} - \psi^f \xi^u p^u = 0 && (32)\\
\pi^s_{q^{su}} &= p^u - \frac{\partial C^s\left(q^{su} + q^{se};\theta^s\right)}{\partial q^{su}} - t^u - \psi^{su}\xi^u p^u - \tau^u = 0 && (33)\\
\pi^s_{q^{se}} &= p^e - (1+\tau^e)\left(\frac{\partial C^s\left(q^{su} + q^{se};\theta^s\right)}{\partial q^{se}} + t^e\right) - \left(\psi^{se}\right)\left(\xi^e\right)p^e, && (34)
\end{aligned}$$

where $\psi^f = \frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f}\frac{q^f}{\left(Q^f + Q^{su}\right)}$ is the conjectural elasticity for Florida processors, $\xi^u = -\frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\frac{\left(Q^f + Q^{su}\right)}{p^u\left(Q^f + Q^{su}\right)}$ is the flexibility of demand in the U.S. market, $\psi^{su} = \frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^{su}}\frac{q^{su}}{\left(Q^f + Q^{su}\right)}$ is the conjectural elasticity of a São Paulo firm exporting to the United States, $\psi^{se} = \frac{\partial Q^{se}}{\partial q^{se}}\frac{q^{se}}{Q^{se}}$ is the conjectural elasticity of a São Paulo firm exporting to the European Union, and $\xi^e = \left(-\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{Q^{se}}{p^e\left(Q^{se}\right)}\right)$ is the flexibility of demand in the European Union market.

Next, we specify the zero-profit conditions by incorporating the number of firms and redefining aggregate quantities as firm-level output times the number of firms ($Q^f = N^f q^f$, $Q^{su} = N^s q^{su}$, and $Q^{se} = N^s q^{se}$), where N^f and N^s are the number of firms in Florida and São Paulo respectively. The zero profit conditions are given by

$$\pi^{of} = p^u \left(N^f q^f + N^s q^{su}\right) q^f - C^f \left(q^f; \theta^f\right) - f^f = 0 \tag{35}$$

$$\pi^{os} = \left(p^u \left(N^f q^f + N^s q^{su}\right) - \tau^u\right) q^{su} + \frac{p^e \left(N^s q^{se}\right)}{(1+\tau^e)} q^{se} \tag{36}$$
$$-C^s \left(q^{su} + q^{se}; \theta^s\right) - t^u q^{su} - t^e q^{se} - f^s = 0$$

Since the demand functions are downward sloping and cost functions are convex, the second-order conditions for a maximum are satisfied, yielding a unique solution. If we know the functional forms for the demand and cost functions, we can solve equations (32) - (36) simultaneously to obtain solutions for q^f, q^{su}, q^{se}, N^f, and N^s.

3.2.1 Comparative Statics

Since we consider general functional forms for the demand and cost functions, we totally differentiate (32) - (36) to analyze the impact of a change in the U.S. and EU tariffs (τ^u and τ^e) and productivity parameters (θ^f and θ^s) on q^f, q^{su}, q^{se}, N^f, and N^s. This differentiation yields a system of five equations and five unknowns, written in the form $Ax = d$:

$$\begin{bmatrix} \pi^f_{q^f q^f} & \pi^f_{q^f q^{su}} & 0 & \pi^f_{q^f N^f} & \pi^f_{q^f N^s} \\ \pi^s_{q^{su} q^f} & \pi^s_{q^{su} q^{su}} & \pi^s_{q^{su} q^{se}} & \pi^s_{q^{su} N^f} & \pi^s_{q^{su} N^s} \\ 0 & \pi^s_{q^{se} q^{su}} & \pi^s_{q^{se} q^{se}} & 0 & \pi^s_{q^{se} N^s} \\ \pi^{of}_{q^f} & \pi^{of}_{qsu} & 0 & \pi^{of}_{N^f} & \pi^{of}_{N^s} \\ \pi^{os}_{q^f} & \pi^{os}_{qsu} & \pi^{os}_{q^{se}} & \pi^{os}_{N^f} & \pi^{os}_{N^s} \end{bmatrix} \begin{bmatrix} dq^f \\ dq^{su} \\ dq^{se} \\ dN^f \\ dN^s \end{bmatrix} = - \begin{bmatrix} \pi^f_{q^f \theta^f} d\theta^f \\ \pi^s_{q^{su} \tau^u} d\tau^u + \pi^s_{q^{su} \theta^s} d\theta^s \\ \pi^s_{q^{se} \tau^e} d\tau^e + \pi^s_{q^{se} \theta^s} d\theta^s \\ \pi^{of}_{\theta^f} d\theta^f \\ \pi^{os}_{\tau^u} d\tau^u + \pi^{os}_{\tau^e} d\tau^e + \pi^{os}_{\theta^s} d\theta^s \end{bmatrix}.$$

With a system of five equations and five variables, the comparative static results are complex with several opposing forces making it difficult to unambiguously sign the results. Consequently, the comparative static results are quantified numerically in the empirical analysis section.

Next, we analyze the welfare impacts of a reduction in the U.S. and EU tariffs and productivity shocks on the United States, the European Union, and São Paulo. For the United States, welfare is comprised of only consumer surplus and tariff revenues because producer surplus in zero due to the zero-profit condition (35) (Bowen, Hollander, and Viaene, 2012):

$$W^u\left(Q^u, Q^{su}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \int p^u\left(Q^u\right) dQ^u - p^u\left(Q^u\right) Q^u + \tau^u Q^{su}, \tag{37}$$

The São Paulo welfare is zero because of the zero-profit condition (36) and zero consumer surplus since all production is exported.

EU welfare consists of consumer surplus and tariff revenues (producer surplus is zero due to no production):

$$W^e\left(Q^u, Q^{su}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \int p^e\left(Q^{se}\right) dQ^{se} - p^e\left(Q^{se}\right) Q^{se} + p^e\left(Q^{se}\right) \tau^e Q^{se}. \tag{38}$$

Welfare Analysis of a Reduction in the U.S. Tariff

To determine the effects of a reduction in the U.S. tariff on U.S. welfare, we totally differentiate (37) with respect to τ^u:

$$\frac{dW^u(\cdot)}{d\tau^u} = \underbrace{-\frac{\partial p^u}{\partial Q^u}\frac{\partial Q^u}{\partial \tau^u} Q^u}_{\text{CS }(-)} + \underbrace{\underbrace{\frac{\partial Q^{su}}{\partial \tau^u}\tau^u}_{-} + \underbrace{Q^{su}}_{+}}_{\text{TR }(?)}. \tag{39}$$

A reduction in the U.S. import tariff leads to more imports from São Paulo resulting in a decrease in the U.S. orange juice price. Consumer surplus (CS) increases because of higher consumption due to a lower price. However, the change in tariff revenues (TR) could be positive or negative depending on whether or not $\frac{\partial Q^{su}}{\partial \tau^u}\tau^u$ outweighs Q^{su}, which depends on where the initial position of the tariff is on the Laffer curve. Hence the net welfare effect could be positive or negative. However, because the gain in consumer surplus will most likely outweigh the loss in tariff revenues, the US welfare is likely to increase.

The US tariff reduction will expand São Paulo's exports to the United States, which will adversely impact the profitability of Florida's processors and cause exit of firms until profits are nonnegative. However, expansion of São Paulo's exports will augment the profits of São

Paulo's processors in the short run. This leads to entry of firms which drives profits to zero in the long run.

To analyze the impacts of a reduction in the U.S. tariff on EU welfare, we totally differentiate (38) with respect to τ^u:

$$\frac{dW^e\left(\cdot\right)}{d\tau^u} = \underbrace{-Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^u}}_{\text{CS }(+)} + \underbrace{\left(Q^{se}\frac{\partial p^e}{\partial Q^{se}} + p^e\right)\tau^e\frac{\partial Q^{se}}{\partial \tau^u}}_{\text{TR }(+)}. \tag{40}$$

A reduction in the U.S. tariff τ^u makes São Paulo orange juice in the United States relatively cheaper than in the European Union, which causes São Paulo to divert its exports from the European Union to the United States. The decline in exports to the European Union leads to a higher price, which lowers the consumption and reduces consumer surplus. With less imports and τ^e unchanged, tariff revenues to the European government decreases. Consequently, the European Union incurs net welfare loss.

Welfare Analysis of a Reduction in the EU Tariff

To analyze the effect of a change in the European tariff on EU welfare, we totally differentiate (38) with respect to τ^e:

$$\frac{dW^e\left(\cdot\right)}{d\tau^e} = \underbrace{-Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^e}}_{\text{CS }(-)} + \underbrace{\left(Q^{se}\frac{\partial p^e}{\partial Q^{se}} + p^e\right)\tau^e\frac{\partial Q^{se}}{\partial \tau^e} + p^e Q^{se}}_{\text{TR }(?)}. \tag{41}$$

With a reduction in the EU tariff, São Paulo processors expand their exports to the European Union and reduce exports to the United States. Higher exports to the European Union lowers the EU price leading to more consumption and higher consumer surplus. The change in tariff revenues could be positive or negative contingent on the initial location of the tariff on the Laffer curve. Consequently, the change in welfare is ambiguous. However, since the gain in consumer surplus will most likely outweigh the loss in tariff revenues, EU welfare is likely to increase.

The EU tariff reduction will expand São Paulo's exports to the European Union, leading to profitability in the short run. However, this causes entry of firms which drives profits to zero in the long run. The redirection of exports by São Paulo from the United States to the European Union will benefit the Florida processors, leading to production expansion and profitability in the short run. This will provide incentive for new firms to enter until profits are driven to zero in the long run.

To obtain the impact of a reduction in the EU tariff τ^eon U.S. welfare, we totally differentiate (37) with respect to τ^e:

$$\frac{dW^u(\cdot)}{d\tau^e} = \underbrace{-Q^u \frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \tau^e}}_{\text{CS } (+)} + \underbrace{\tau^u \frac{\partial Q^{su}}{\partial \tau^e}}_{\text{TR } (+)}. \tag{42}$$

The EU tariff reduction will crowd out exports from the United States to the European Union, which will increase the price and lower the consumption in the United States. This reduces the consumer surplus. With lower imports and U.S. tariff τ^u unchanged, tariff revenues decline. Consequently, the United States experiences welfare loss.

Welfare Analysis of São Paulo Productivity Shock

Diffusion of technology from the Florida to São Paulo will lead to rapid advances in productivity. Due to this technological progress, São Paulo producers will use inputs more efficiently, reduce their production costs, and expand output. We analyze how an increase in São Paulo's productivity relative to that of Florida affects welfare in the United States, São Paulo, and the European Union.

We obtain the change in U.S. welfare by totally differentiating (37) with respect to θ^s:

$$\frac{dW^u(\cdot)}{d\theta^s} = \underbrace{-\frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \theta^s} Q^u}_{\text{CS } (+)} + \underbrace{\tau^u \frac{\partial Q^{su}}{\partial \theta^s}}_{\text{TR } (+)}. \tag{43}$$

The increase in São Paulo's productivity leads to an expansion of production and exports by São Paulo processors. Higher exports to the United States lead to a decline in the U.S. price of orange juice. Consumer surplus increases because of more consumption and lower prices. With the U.S. tariff unchanged, tariff revenues rise because of higher imports from São Paulo. Thus, an increase in São Paulo's productivity leads to a net welfare gain for the United States.

For São Paulo, due to an increase in productivity, total orange juice production will increase and it will lead to more exports to both the United States and European Union. In the short run, profits are positive leading to a positive gain in welfare; however, this leads to entry of more firms which will drive profits to zero in the long-run. With more efficient production, São Paulo processors will augment their export to the United States, which will negatively impact the production and profitability of Florida processors, causing firms to exit until the profits are nonnegative.

We obtain the change in EU welfare by totally differentiating (38) with respect to θ^s:

$$\frac{dW^e(\cdot)}{d\theta^s} = \underbrace{-Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \theta^s}}_{\text{CS}(+)} + \underbrace{\left(Q^{se}\frac{\partial p^e}{\partial Q^{se}} + p^e\right)\tau^e\frac{\partial Q^{se}}{\partial \theta^s}}_{\text{TR}(+)}. \tag{44}$$

As a result of higher productivity, São Paulo exports more to the European Union, which lowers EU orange juice price and increases consumption. This causes EU consumer surplus to increase. Since the EU tariff remains fixed, with more imports, EU tariff revenues increase. Consequently, the net change in EU welfare is positive.

3.3 Empirical Analysis

This section presents the system of empirical equations for the simulation analysis, describes data and calibration of the model, and discusses the simulation strategy and results.

3.3.1 Empirical Model

To carry out the empirical analysis, we must specify specific functional forms for the marginal cost and inverse demand functions. The firm-level marginal cost functions for Florida (mc^f) and São Paulo (mc^s) processors are defined as

$$mc^f = \frac{\partial C^f}{\partial q^f} = \gamma_0^f + \gamma_1^f q^f \tag{45}$$

$$mc^s = \frac{\partial C^s}{\partial q^{su}} = \gamma_0^s + \gamma_1^s\left(q^{su} + q^{se}\right) + t^u \tag{46}$$

$$mc^s = \frac{\partial C^s}{\partial q^{se}} = \gamma_0^s + \gamma_1^s\left(q^{su} + q^{se}\right) + t^e, \tag{47}$$

where γ_j^i ($i = u, e; j = 0, 1$) are intercept and slope parameters of the marginal cost function. Since São Paulo exports to the United States and European Union, it has two marginal cost functions with identical cost of production, but different transport costs t^u and t^e.

The U.S. and EU inverse demand functions are defined as

$$p^u = \delta_0^u + \delta_1^u \left(Q^f + Q^{su}\right) \tag{48}$$

$$p^e = \delta_0^e + \delta_1^e Q^{se}, \tag{49}$$

where δ_j^i ($i = u, e$; $j = 0, 1$) represent the intercept and slope parameters of the demand function.

From the first-order conditions (32) - (34), marginal cost functions (45) - (47), and the demand elasticities from (48) and (49), we derive the aggregate supply relations by incorporating the number of firms:

$$p^u = \gamma_0^f + \gamma_1^f N^f q^f + \psi^f \delta_1^u \left(N^f q^f + N^s q^{su}\right) \tag{50}$$

$$p^u = \gamma_0^{su} + \gamma_1^{su} \left(N^s q^{su} + N^s q^{se}\right) + t^u + \psi^{su} \delta_1^u \left(N^f q^f + N^s q^{su}\right) + \tau^u \tag{51}$$

$$p^e = \left(1 + \tau^e\right) \left(\gamma_0^{se} + \gamma_1^{se} \left(N^s q^{su} + N^s q^{se}\right) + t^e\right) + \psi^{se} \delta_1^e \left(N^s q^{se}\right). \tag{52}$$

We redefine the zero-profit equations (35) and (36) by including the marginal cost functions:

$$\pi^{of} = p^u q^f - \left(\gamma_0^f + \frac{\gamma_1^f}{2} q^f\right) q^f - f^f \tag{53}$$

$$\begin{aligned} \pi^{os} = {} & \left(p^u - \tau^u\right) q^{su} + \frac{p^e}{\left(1 + \tau^e\right)} q^{se} \\ & -(\gamma_0^s q^{su} + \frac{\gamma_1^s}{2} \left(q^{su}\right)^2 + 2\gamma_1^s \left(q^{su}\right) \left(q^{se}\right) + \gamma_0^s q^{se} \\ & + \frac{\gamma_1^s}{2} \left(q^{se}\right)^2 + t^u q^{su} + t^e q^{se} + f^s) \end{aligned} \tag{54}$$

Equations (48) - (54) represent the system of seven simultaneous equations with seven endogenous variables p^u, p^e, q^f, q^{su}, q^{se}, N^f, and N^s, which are used for the simulation analysis.

3.3.2 Calibration and Data

Before conducting the simulation analysis, we need to parameterize the supply relations and demand functions using price, quantity, tariff, and transport cost data and conjectural, supply, and demand elasticities. We use the data averaged over the period 2007 - 2011 to parameterize the coefficients in the supply relations and demand functions.

Data for prices, quantities, tariffs, and transport costs data are collected from various sources. The total U.S. consumption, Florida supply, São Paulo export values and quantity of exports to the United States and European Union are obtained from FAOSTAT (2014). The U.S. orange juice price is calculated from the Florida Department of Citrus (2012), the Bureau of Labor Statistics (2012), and FAOSTAT (2014). The EU price is calculated by dividing the value of imports by quantity of imports from São Paulo. To calculate the real prices for orange juice, nominal prices are divided by their respective consumer price indices. The U.S. and EU consumer price indices are collected from the World Bank (2014). The U.S. and EU import tariffs are obtained from the WTO (2014). Transportation cost data between São Paulo and the United States and São Paulo and the European Union is calculated as the difference between Cost, Insurance and Freight (CIF) and Freight On Board (FOB) values.

Luckstead, Devadoss, and Mittelhammer (2014a) estimate the conjectural elasticities for Florida firms as 0.46 and for São Paulo firms' sales in the United States as 0.31 and São Paulo firms' sales in the European Union as 1.0. They also estimate the supply flexibility for Florida producers as 1.55 and São Paulo producers to the United States and European Union as 0.52 and 0.71, respectively.[2] Based on the price, quantity, and conjectural elasticities and supply flexibilities, the intercept and slope parameters are calibrated as -2.91 and 0.17 for Florida firms and 1.00 and 0.50 for São Paulo firms, respectively. The transport cost parameters for São Paulo to the United States and São Paulo to European Union are calibrated as 1.00 and 1.30 respectively.

Brown, Spreen, and Lee (2004) find the U.S. and EU demand elasticity for frozen concentrated orange juice (FCOJ) as -0.70 and -0.41 respectively. Brown (2010) calculates the EU demand elasticity for orange juice at -0.46 and -0.60 based on the Ordinary Least Squares Estimation method and the Instrumental Variable Estimation method, respectively. Luckstead, Devadoss, and Mittelhammer (2014a) estimate the EU price elasticity of demand for orange juice as -0.88 (flexibility as -1.73) and estimate the U.S. price elasticity of demand as -0.70 (flexibility as -1.44). We utilize these elasticity estimates as a basis to calibrate the intercept

[2]These flexibilities are not reported in Luckstead, Devadoss, and Mittelhammer (2014a) and were obtained through correspondence with the author.

and slope parameters of the U.S. demand function at 11.65 and -0.26 and of EU demand function at 5.67 and -0.14.

3.3.3 Simulation and Results

Once the Doha Development Round agreement is completed, the U.S. and the EU import tariffs will be reduced. In addition, if the Free Trade Areas of America agreement is reached, the U.S. tariff could be phased out. Therefore, it is essential to analyze the impacts of free trade by eliminating the U.S. and EU tariffs on prices, quantities, market structure, and welfare. Also, São Paulo producers have been improving their processing technology to compete effectively with Florida producers. These technological advancements augment the competition and have implications for survivability of marginal firms, supply, market structure, and prices. Consequently, it is worth analyzing the effects of productivity shocks on the orange juice markets.

For the simulation analysis we numerically solve the system of seven equations (48) - (54) with seven endogenous variables (p^u, p^e, q^f, q^{su}, q^{se}, N^f, and N^s). We run the baseline scenario and three counterfactual scenarios. The three counterfactuals are 1) elimination of the U.S. tariff, 2) elimination of the European Union tariff, and 3) an exogenous increase in São Paulo processors' productivity relative to Florida processors' productivity. These productivity changes are implemented by shifting and rotating the São Paulo processors' marginal cost function through a 50% decrease in the intercept and a 10% decrease in the slope. The values of endogenous variables under the counterfactual scenarios are compared to those of the baseline values to quantify the impacts. Table 6 summarizes the simulation results of the impacts of U.S. and EU import tariff elimination. Table 7 presents the results of an increase in São Paulo processors' productivity.

Scenario 1: Elimination of the U.S. tariff causes São Paulo to divert exports from the European Union (11.87% decline) to the United States (48.25% increase). As a result of higher U.S. imports, Florida processors decrease output by 3.34%. The increase in total U.S. sales (sum of Florida and São Paulo sales) leads to 2.04% decrease in the U.S. price. Since São Paulo diverts its exports from the European Union, sales in the European Union decline by 11.87%,

Table 6: Impacts of Tariff Elimination

	Tariff elimination by	
Variables	United States	European Union
U.S. price (% change)	-2.04	2.13
EU price (% change)	2.18	-4.13
Florida Quantity (% change)	-3.34	3.48
São Paulo exports to the United States (% change)	48.25	-50.26
São Paulo exports to European Union (% change)	-11.87	22.44
Change in Number of Firms in Florida	-1.00	1.00
Change in Number of Firms in São Paulo	1.00	1.00
Change in Total welfare ($ millions)	172.90	-284.00
Change in U.S. consumer surplus ($ millions)	240.20	-250.20
Change in Tariff Revenue ($ millions)	-67.20	-33.80
Change in Total welfare ($ millions)	-121.40	-334.70
Change in EU consumer surplus ($ millions)	-64.20	121.50
Change in Tariff Revenue ($ millions)	-57.20	-456.10

leading to an increase in EU price by 2.18%. The decrease in production affects the profitability of Florida processors, which causes one processor to exit the industry. In contrast, since São Paulo processors find it profitable to increase production and exports, one new firm enters into the orange juice market in São Paulo.

The welfare analysis, based on equation (39), shows that lower price and higher consumption arising from elimination of the U.S. tariff cause the consumer surplus to increase by $240.20 million and tariff revenues to decrease by $61.20 million. Consequently, the net welfare gain is $172.9 million. Since U.S. tariff reduction lowers consumption and increases the price in the European Union, consumer surplus falls by $64.2 million and tariff revenue also goes down by $57.2 million, leading to an EU total welfare loss of $121.5 million (refer to equation (40)).

Scenario 2: Elimination of the EU tariff causes São Paulo processors to increase their exports to the European Union by 22.4% and reduce their exports to the United States by 50.26%. The reduction in São Paulo processors' sales in the United States benefits Florida processors who increase their production by 3.48%. However, total U.S. sales (sum of Florida processors' and São Paulo processors' sales) declines, resulting in a 2.13% increase in the U.S. price. Total sales in the European Union increase by 22.4%, leading to a 4.13% decrease in EU price. The increase in production both in São Paulo and Florida results in the entry of one processor in both São Paulo and Florida.

The reduction in the EU tariff causes the São Paulo processors to divert their exports from the United States to the European Union. As a result, total consumption of orange juice in the United States declines and price increases, leading to a consumer surplus loss of $250.2 million and tariff revenue loss of $33.8 million based on equation (42)). Consequently, total U.S. welfare falls by $284 million. Elimination of the EU tariff causes the price to decline and consumption to rise, which leads to consumer surplus gain of $121.5 million (refer to equation (41)). However, because of the reduction in the tariff, tariff revenues fall by $456.10 million. Since the gain in consumer surplus is less than the loss in tariff revenue, the overall welfare loss is $334.7 million.

Scenario 3: Due to technological advancements in processing, orange juice production in São Paulo increases. Here we discuss the results of the impacts of São Paulo productivity shock on prices, quantities, number of firms, trade flows and welfare. With higher productivity, São Paulo processors augment their output and export more to both the United States (54.41%) and the European Union (8.52%). As a result, output of Florida firms decreases by 3.77%. The increase in total sales in the United States leads to a 2.3% decline in the U.S. price. In the European Union, total sales increases by 8.52% resulting in a 1.57% decline in the EU price. The increase in production and profitability leads to one new firm entering the São Paulo industry, whereas the decrease in output and profitability causes one firm to exit the Florida orange juice industry.

The increased sales and lower prices in the United States leads to a consumer surplus gain of $271 million and a tariff revenue increase of $11 million. As a result, U.S. total welfare rises by $282 million (refer to equation (43)). Similarly, higher consumption and a lower price in the European Union augment consumer surplus by $46.1 million and tariff revenues by $41.1 million, which increases EU total welfare by $87.2 million (based on equation (44)).

Table 7: Impacts of an Increase in Sao Paulo Processors' Productivity

	Productivity increase in
Variables	São Paulo
U.S. price (% change)	-2.30
EU price (% change)	-1.57
Florida Quantity (% change)	-3.77
São Paulo exports to the United States (% change)	54.44
São Paulo exports to European Union (% change)	8.52
Difference in number of firms in Florida	-1.00
Difference in number of firms in São Paulo	1.00
Change in Total welfare ($ millions)	282.00
Change in U.S. consumer surplus ($ millions)	271.00
Change in Tariff Revenue ($ millions)	11.00
Change in Total welfare ($ millions)	87.20
Change in EU consumer surplus ($ millions)	46.10
Change in Tariff Revenue ($ millions)	41.10

These simulation results are consistent with the comparative static results of the theoretical analysis.

3.4 Conclusions

The orange juice industry is highly concentrated in Florida and São Paulo, leading to oligopolistic competition with a few firms exerting market power over sales and prices. About 95% of juice produced in Florida is consumed domestically in the United States, whereas 99% of the São Paulo juice production is exported. The United States and European Union are the two leading consumers of orange juice in the world with the European Union accounting for about 58% of total world orange juice imports. Both the United States and European Union impose tariffs on their orange juice imports.

Based on new trade theory, we develop a strategic trade model of U.S., EU, and São Paulo orange juice markets. We endogenize firm entry and exit by incorporating zero-profit conditions for Florida and São Paulo processors. We theoretically analyze the effects of changes in U.S. and EU tariffs and a productivity shock on the orange juice market. For the simulation analysis, we specify a system of simultaneous equations based on the theoretical model. The results shows that elimination of the U.S. tariff leads to more U.S. imports from São Paulo, resulting in a decrease in the U.S. price and an increase in U.S. welfare. The U.S. tariff reduction causes one firm to enter in São Paulo and one firm to exit in Florida. Due to export diversion from the European Union to the United States, there is a net welfare loss in the European Union. As a result of the elimination of the EU tariff, EU imports increase and the price decreases, which leads to consumer surplus gain and tariff revenue loss. With less imports from São Paulo, the U.S. domestic price increases, leading to a net decline in U.S. welfare. As a result, one firm enters the market in both Florida and São Paulo. An increase in São Paulo's productivity results in more production and exports to the United States and European Union, which augments the welfare in both the United States and the European Union. These results corroborate the analytical results of the theoretical model.

Free trade and technological advancement in orange juice processing in São Paulo lead to increased efficiency and production. As a result, São Paulo processors export more to the United States, reducing domestic juice production by Florida processors. They also increase their exports to the European Union. Consequently, their market shares in both the United States and European Union increase. Thus, Florida processors face stiff competition and lose market share to São Paulo processors. However, due to increased competition, orange juice price decreases and U.S. consumer surplus increases. Also, European Union consumers gain from increased exports by São Paulo processors. Given the Doha Round agreement, it is imperative on the part of Florida processors to increase their efficiency if they are to maintain their competitive status. Similarly, Florida orange growers should also enhance their productivity to increase orange production since São Paulo has a comparative advantage in orange production. Otherwise, Florida orange juice processors will find it difficult to compete because oranges are the single most important intermediate input in juice production. To be competitive, Florida processors should also invest in cost-cutting technology in juice production.

3.5 Supplementary Material: Math Derivations

Profit Functions

The Florida firm-level profit function is given by

$$\pi^f = p^u\left(Q^f + Q^{su}\right)q^f - C^f\left(q^f;\theta^f\right) - f^f, \tag{55}$$

The São Paulo firm-level profit function is given by

$$\pi^s = \left(p^u\left(Q^f + Q^{su}\right) - \tau^u\right)q^{su} + \frac{p^e\left(Q^{se}\right)}{(1+\tau^e)}q^{se} - C^s\left(q^{su} + q^{se};\theta^s\right) - t^u q^{su} - t^e q^{se} - f^s, \tag{56}$$

First-Order Conditions

In this section, we derive the first-order conditions from the profit functions (55) and (56) of Florida and São Paulo with respect to firm-level quantities, q^f, q^{su}, and q^{se}.

Florida:

The first-order condition for Florida is derived with respect to q^f is derived as:

$$\begin{aligned}
\pi^f_{q^f} &= q^f \frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f} + p^u\left(Q^f + Q^{su}\right) - \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f} = 0\\
p^u\left(Q^f + Q^{su}\right) &= \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f} - q^f\frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f}\\
p^u\left(Q^f + Q^{su}\right) &= \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}\\
&\quad - q^f\frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\frac{\left(Q^f + Q^{su}\right)}{\left(Q^f + Q^{su}\right)}\frac{p^u\left(Q^f + Q^{su}\right)}{p^u\left(Q^f + Q^{su}\right)}\frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f}\\
p^u\left(Q^f + Q^{su}\right) &= \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}\\
&\quad - \frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\frac{\left(Q^f + Q^{su}\right)}{p^u\left(Q^f + Q^{su}\right)}\frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f}\frac{q^f}{\left(Q^f + Q^{su}\right)}p^u\left(Q^f + Q^{su}\right)\\
p^u\left(Q^f + Q^{su}\right) &= \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}\\
&\quad + \frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f}\frac{q^f}{\left(Q^f + Q^{su}\right)}\left(-\frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\frac{\left(Q^f + Q^{su}\right)}{p^u\left(Q^f + Q^{su}\right)}\right)p^u\left(Q^f + Q^{su}\right)
\end{aligned}$$

Define $\psi^f = \dfrac{\partial\left(Q^f + Q^{su}\right)}{\partial q^f}\dfrac{q^f}{\left(Q^f + Q^{su}\right)}$ as the conjectural elasticity of a Florida firm and $\xi^u = -\dfrac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)}\dfrac{\left(Q^f + Q^{su}\right)}{p^u\left(Q^f + Q^{su}\right)}$ as the flexibility in the U.S. market.

$$p^u\left(Q^f + Q^{su}\right) - \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f} - \psi^f\xi^u p^u\left(Q^f + Q^{su}\right) = 0 \tag{57}$$

São Paulo to United States:

The first-order condition for São Paulo with respect to q^{su}:

$$\pi^s_{q^{su}} = q^{su}\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^{su}} + \left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right)$$
$$-\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} - t^u = 0$$
$$\left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right) = \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} + t^u - q^{su}\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^{su}}$$
$$\left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right) = \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} + t^u$$
$$-q^{su}\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\left(Q^f+Q^{su}\right)}{\left(Q^f+Q^{su}\right)}\frac{p^u\left(Q^f+Q^{su}\right)}{p^u\left(Q^f+Q^{su}\right)}\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^{su}}$$
$$\left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right) = \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} + t^u$$
$$-\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\left(Q^f+Q^{su}\right)}{p^u\left(Q^f+Q^{su}\right)}\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^{su}}\frac{q^{su}}{\left(Q^f+Q^{su}\right)}p^u\left(Q^f+Q^{su}\right)$$
$$\left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right) = \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} + t^u$$
$$+\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^{su}}\frac{q^{su}}{\left(Q^f+Q^{su}\right)}\left(-\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\left(Q^f+Q^{su}\right)}{p^u\left(Q^f+Q^{su}\right)}\right)p^u\left(Q^f+Q^{su}\right)$$

Define $\psi^{su} = \frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^{su}}\frac{q^{su}}{\left(Q^f+Q^{su}\right)}$ as the conjectural elasticity of São Paulo firm exporting firm to the United States and

$\xi^u = \left(-\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\left(Q^f+Q^{su}\right)}{p^u\left(Q^f+Q^{su}\right)}\right)$ as flexibility in the U.S. market.

$$\left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right) = \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} + t^u + \psi^{su}\xi^u p^u\left(Q^f+Q^{su}\right)$$
$$p^u\left(Q^f+Q^{su}\right) - \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}} - t^u - \psi^{su}\xi^u p^u\left(Q^f+Q^{su}\right) - \tau^u = 0 \qquad (58)$$

São Paulo to the European Union:

The first-order condition for São Paulo with respect to q^{se}:

$$\pi^s_{q^{se}} = \frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial q^{se}} + \frac{p^e\left(Q^{se}\right)}{(1+\tau^e)} - \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}} - t^e = 0$$
$$\frac{p^e\left(Q^{se}\right)}{(1+\tau^e)} = \frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}} + t^e - \frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial q^{se}}$$
$$p^e\left(Q^{se}\right) = (1+\tau^e)\left(\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}} + t^e - \frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial q^{se}}\right)$$
$$p^e\left(Q^{se}\right) = (1+\tau^e)\left(\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}} + t^e\right)$$

$$-q^{se}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{Q^{se}}{Q^{se}}\frac{p^e\left(Q^{se}\right)}{p^e\left(Q^{se}\right)}\frac{\partial Q^{se}}{\partial q^{se}}$$

$$p^e\left(Q^{se}\right)=\left(1+\tau^e\right)\left(\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}}+t^e\right)$$
$$-\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{Q^{se}}{p^e\left(Q^{se}\right)}\frac{\partial Q^{se}}{\partial q^{se}}\frac{q^{se}}{Q^{se}}p^e\left(Q^{se}\right)$$

$$p^e\left(Q^{se}\right)=\left(1+\tau^e\right)\left(\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}}+t^e\right)$$
$$+\frac{\partial Q^{se}}{\partial q^{se}}\frac{q^{se}}{Q^{se}}\left(-\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\frac{Q^{se}}{p^e\left(Q^{se}\right)}\right)p^e\left(Q^{se}\right)$$

Define $\psi^{se}=\dfrac{\partial Q^{se}}{\partial q^{se}}\dfrac{q^{se}}{Q^{se}}$ as the conjectural elasticity of São Paulo firm exporting European Union and $\xi^e=\left(-\dfrac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\dfrac{Q^{se}}{p^e\left(Q^{se}\right)}\right)$ as the flexibility in European Union market:

$$p^e\left(Q^{se}\right)-\left(1+\tau^e\right)\left(\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}}+t^e\right)-\psi^{se}\xi^e p^e\left(Q^{se}\right)=0 \tag{59}$$

Zero-Profit Conditions

The two firm-level zero-profit conditions for Florida and São Paulo are given respectively by

$$\pi^{of}=p^u\left(N^f q^f+N^s q^{su}\right)q^f-C^f\left(q^f;\theta^f\right)-f^f=0 \tag{60}$$

$$\pi^{os}=\left(p^u\left(N^f q^f+N^s q^{su}\right)-\tau^u\right)q^{su}+\frac{p^e\left(N^s q^{se}\right)}{\left(1+\tau^e\right)}q^{se} \tag{61}$$
$$-C^s\left(q^{su}+q^{se};\theta^s\right)-t^u q^{su}-t^e q^{se}-f^s=0$$

Second-Order Conditions

Since the demand functions are downward sloping and the cost function is convex, we know the reaction function constitute a solution because the profit functions are globally concave implying the second-order conditions for a maximum are satisfied. To derive analytical results, we assume Cournot competition. The second-order conditions are given below.

Florida

We use equation (57) to derive:

$$\pi^f_{q^f q^f}=q^f\frac{\partial^2 p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)\partial\left(Q^f+Q^{su}\right)}\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^f}+\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}$$
$$+\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}\frac{\partial\left(Q^f+Q^{su}\right)}{\partial q^f}-\frac{\partial^2 C^f\left(q^f;\theta^f\right)}{\partial q^f\partial q^f}<0$$

Under Cournot competition $\dfrac{\partial\left(Q^f+Q^{su}\right)}{\partial q^f}=1$, Therefore, the derivative of $\pi^f_{q^f}$ with respect to q^f is

$$\pi^f_{q^f q^f} = q^f \frac{\partial^2 p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)\partial\left(Q^f + Q^{su}\right)} + 2\frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)} - \frac{\partial^2 C^f\left(q^f;\theta^f\right)}{\partial q^f \partial q^f} < 0 \tag{62}$$

We use equation (57) to derive:

$$\pi^f_{q^f q^{su}} = q^f \frac{\partial^2 p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)\partial\left(Q^f + Q^{su}\right)} \frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^{su}} + \frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)} \frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^{su}} < 0$$

Under Cournot competition $\frac{\partial\left(Q^f + Q^{su}\right)}{\partial q^{su}} = 1$,

Therefore, the derivative of $\pi^f_{q^f}$ with respect to q^{su} is

$$\pi^f_{q^f q^{su}} = q^f \frac{\partial^2 p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)\partial\left(Q^f + Q^{su}\right)} + \frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)} < 0 \tag{63}$$

The derivative of $\pi^f_{q^f}$ with respect to q^{se} is

$$\pi^f_{q^f q^{se}} = 0 \tag{64}$$

The aggregate quantities are redefined as

$$Q^f = N^f q^f$$

$$Q^s = Q^{su} + Q^{se} = N^s q^{su} + N^s q^{se} = N^s\left(q^{su} + q^{se}\right)$$

$$Q^u = Q^f + Q^{su}$$

where N^f and N^s are the number of orange juice processors in Florida and São Paulo respectively.

The equation (57) is redefined as:

$$\pi^f_{q^f} = q^f \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} + p^u\left(N^f q^f + N^s q^{su}\right) - \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f} = 0$$

We use the above equation to derive:

$$\pi^f_{q^f N^f} = q^f \frac{\partial^2 p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^f q^f}}_{=1} \underbrace{\frac{\partial N^f q^f}{\partial N^f}}_{=q^f} + \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial q^f}{\partial N^f}}_{=0} + \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^f q^f}}_{=1} \underbrace{\frac{\partial N^f q^f}{\partial N^f}}_{=q^f}$$

$$\pi^f_{q^f N^f} = q^f \frac{\partial^2 p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)\partial\left(N^f q^f + N^s q^{su}\right)} q^f + \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} q^f$$

We can therefore define the SOC for (57) with respect to N^f as

$$\pi^f_{q^f N^f} = q^f \left(q^f \frac{\partial^2 p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right) \partial \left(N^f q^f + N^s q^{su}\right)} + \frac{\partial p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right)} \right) < 0 \quad (65)$$

We use equation (57) to derive:

$$\pi^f_{q^f N^s} = q^f \frac{\partial^2 p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right) \partial \left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial \left(N^f q^f + N^s q^{su}\right)}{\partial N^s q^{su}}}_{=1} \underbrace{\frac{\partial N^s q^{su}}{\partial N^s}}_{=q^{su}}$$

$$+ \frac{\partial p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial q^f}{\partial N^{su}}}_{=0} + \frac{\partial p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial \left(N^f q^f + N^s q^{su}\right)}{\partial N^s q^{su}}}_{=1} \underbrace{\frac{\partial N^s q^{su}}{\partial N^u}}_{=q^{su}}$$

$$\pi^f_{q^f N^s} = q^f \frac{\partial^2 p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right) \partial \left(N^f q^f + N^s q^{su}\right)} q^{su} + \frac{\partial p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right)} q^{su}$$

Therefore the derivative of $\pi^f_{q^f}$ with respect to N^s is

$$\pi^f_{q^f N^s} = q^{su} \left(q^f \frac{\partial^2 p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right) \partial \left(N^f q^f + N^s q^{su}\right)} + \frac{\partial p^u \left(N^f q^f + N^s q^{su}\right)}{\partial \left(N^f q^f + N^s q^{su}\right)} \right) < 0 \quad (66)$$

São Paulo

São Paulo SOC for $\pi^s_{q^{su}}$ (equation (58)) with respect to q^f:

$$\pi^s_{q^{su} q^f} = q^{su} \frac{\partial^2 p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right) \partial \left(Q^f + Q^{su}\right)} \underbrace{\frac{\partial \left(Q^f + Q^{su}\right)}{\partial q^f}}_{=1} + \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} \underbrace{\frac{\partial q^{su}}{\partial q^f}}_{=0}$$

$$+ \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} \underbrace{\frac{\partial \left(Q^f + Q^{su}\right)}{\partial q^f}}_{=1} < 0,$$

$$\pi^s_{q^{su} q^f} = q^{su} \frac{\partial^2 p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right) \partial \left(Q^f + Q^{su}\right)} + \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} < 0 \quad (67)$$

São Paulo SOC for $\pi^s_{q^{su}}$ (equation (58)) with respect to q^{su}:

$$\pi^s_{q^{su}} = q^{su} \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} + \left(p^u \left(Q^f + Q^{su}\right) - \tau^u\right) - \frac{\partial C^s \left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su}} - t^u = 0$$

$$\pi^s_{q^{su} q^{su}} = q^{su} \frac{\partial^2 p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right) \partial \left(Q^f + Q^{su}\right)} \underbrace{\frac{\partial \left(Q^f + Q^{su}\right)}{\partial q^{su}}}_{=1} + \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} \underbrace{\frac{\partial q^{su}}{\partial q^{su}}}_{=1}$$

$$+ \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} \underbrace{\frac{\partial q^{su}}{\partial q^{su}}}_{=1} - \frac{\partial^2 C^s \left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su} \partial q^{su}} < 0,$$

$$\pi^s_{q^{su} q^{su}} = q^{su} \frac{\partial^2 p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right) \partial \left(Q^f + Q^{su}\right)} + \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)} + \frac{\partial p^u \left(Q^f + Q^{su}\right)}{\partial \left(Q^f + Q^{su}\right)}$$

$$-\frac{\partial^2 C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}\partial q^{su}}<0,$$

$$\pi^s_{q^{su}q^{su}}=q^{su}\frac{\partial^2 p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)\partial\left(Q^f+Q^{su}\right)}+2\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}-\frac{\partial^2 C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}\partial q^{su}}<0, \tag{68}$$

$$\pi^s_{q^{su}q^{se}}=-\frac{\partial^2 C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}\partial q^{se}}<0 \tag{69}$$

São Paulo SOC for $\pi^s_{q^{su}}$ (equation (58)) with respect to N^f:

$$\pi^s_{q^{su}}=q^{su}\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}+\left(p^u\left(Q^f+Q^{su}\right)-\tau^u\right)-\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}}-t^u=0$$

The above equation is rewritten by incorporating the number of firms as:

$$\pi^s_{q^{su}}=q^{su}\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}+\left(p^u-\tau^u\right)-\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}}-t^u=0$$

$$\pi^s_{q^{su}N^f}=q^{su}\frac{\partial^2 p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)\partial\left(N^fq^f+N^sq^{su}\right)}\underbrace{\frac{\partial\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f\right)}}_{=1}\underbrace{\frac{\partial\left(N^fq^f\right)}{\partial N^f}}_{=q^f}$$

$$+\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}\underbrace{\frac{\partial q^{su}}{\partial N^f}}_{=0}+\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}\underbrace{\frac{\partial\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f\right)}}_{=1}\underbrace{\frac{\partial\left(N^fq^f\right)}{\partial N^f}}_{=q^f}$$

$$\pi^s_{q^{su}N^f}=q^{su}\frac{\partial^2 p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)\partial\left(N^fq^f+N^sq^{su}\right)}q^f+\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}q^f$$

Note: $\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}=\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}$

$$\pi^s_{q^{su}N^f}=q^{su}\frac{\partial^2 p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)\partial\left(N^fq^f+N^sq^{su}\right)}q^f+\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}q^f$$

$$\pi^s_{q^{su}N^f}=q^f\left(q^{su}\frac{\partial^2 p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)\partial\left(N^fq^f+N^sq^{su}\right)}+\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}\right)<0 \tag{70}$$

São Paulo SOC for $\pi^s_{q^{su}}$ (equation (58)) with respect to N^s:

$$\pi^s_{q^{su}N^s}=q^{su}\frac{\partial^2 p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)\partial\left(N^fq^f+N^sq^{su}\right)}\underbrace{\frac{\partial\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^sq^{su}\right)}}_{=1}\underbrace{\frac{\partial\left(N^sq^{su}\right)}{\partial N^s}}_{=q^{su}}$$

$$+\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}\underbrace{\frac{\partial q^{su}}{\partial N^s}}_{=0}+\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}\underbrace{\frac{\partial\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^sq^{su}\right)}}_{=1}\underbrace{\frac{\partial\left(N^sq^{su}\right)}{\partial N^s}}_{=q^{su}}$$

$$\pi^s_{q^{su}N^s}=q^{su}\frac{\partial^2 p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)\partial\left(N^fq^f+N^sq^{su}\right)}q^{su}+\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}q^{su}$$

Note: $\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}=\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}$

$$\pi^s_{q^{su}N^s} = q^{su}\frac{\partial^2 p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)\partial\left(N^f q^f + N^s q^{su}\right)} q^{su} + \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} q^{su}$$

$$\pi^s_{q^{su}N^s} = q^{su}\left(q^{su}\frac{\partial^2 p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)\partial\left(N^f q^f + N^s q^{su}\right)} + \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)}\right) < 0 \tag{71}$$

São Paulo SOC for $\pi^s_{q^{se}}$ (equation (59)) with respect to q^f:

$$\pi^s_{q^{se}q^f} = 0 \tag{72}$$

São Paulo SOC for $\pi^s_{q^{se}}$ (equation (59)) with respect to q^{su}:

$$\pi^s_{q^{se}q^{su}} = -\frac{\partial^2 C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}\partial q^{su}} < 0 \tag{73}$$

São Paulo SOC for $\pi^s_{q^{se}}$ (equation (59)) with respect to q^{se}:

$$\pi^s_{q^{se}q^{se}} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial^2 p^e\left(Q^{se}\right)}{\partial Q^{se}\partial Q^{se}}\underbrace{\frac{\partial Q^{se}}{\partial q^{se}}}_{=1} + \frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\underbrace{\frac{\partial q^{se}}{\partial q^{se}}}_{=1} + \frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\underbrace{\frac{\partial Q^{se}}{\partial q^{se}}}_{=1}\right)$$

$$-\frac{\partial^2 C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}\partial q^{se}} < 0.$$

$$\pi^s_{q^{se}q^{se}} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial^2 p^e\left(Q^{se}\right)}{\partial Q^{se}\partial Q^{se}} + \frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}} + \frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\right) - \frac{\partial^2 C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}\partial q^{se}} <$$

0

$$\pi^s_{q^{se}q^{se}} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial^2 p^e\left(Q^{se}\right)}{\partial Q^{se}\partial Q^{se}} + 2\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}\right) - \frac{\partial^2 C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}\partial q^{se}} < 0$$

Multiply both sides by $(1+\tau^e)$:

$$\pi^s_{q^{se}q^{se}} = q^{se}\frac{\partial^2 p^e\left(Q^{se}\right)}{\partial Q^{se}\partial Q^{se}} + 2\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}} - (1+\tau^e)\frac{\partial^2 C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}\partial q^{se}} < 0 \tag{74}$$

Rewriting equation (59):

$$\pi^s_{q^{se}} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}} + p^e\left(Q^{se}\right)\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}} - t^e = 0$$

$$\pi^s_{q^{se}} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)} + p^e\left(N^s q^{se}\right)\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}} - t^e = 0$$

São Paulo SOC for $\pi^s_{q^{se}}$ (equation (59)) with respect to N^f:

$$\pi^s_{q^{se}N^f} = 0 \tag{75}$$

São Paulo SOC for $\pi^s_{q^{se}}$ (equation (59)) with respect to N^s:

$$\pi^s_{q^{se}N^s} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial^2 p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)\partial\left(N^s q^{se}\right)}\underbrace{\frac{\partial\left(N^s q^{se}\right)}{\partial N^s}}_{=\,q^{se}}\right)$$

$$+\frac{1}{(1+\tau^e)}\left(\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)}\underbrace{\frac{\partial q^{se}}{\partial N^s}}_{=0}+\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)}\underbrace{\frac{\partial\left(N^s q^{se}\right)}{\partial N^s}}_{=q^{se}}\right)$$

$$\pi^s_{q^{se}N^s}=\frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial^2 p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)\partial\left(N^s q^{se}\right)}q^{se}+\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)}q^{se}\right)$$

$$\pi^s_{q^{se}N^s}=\frac{q^{se}}{(1+\tau^e)}\left(q^{se}\frac{\partial^2 p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)\partial\left(N^s q^{se}\right)}+\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)}\right)<0 \tag{76}$$

Differentiation of the Zero-Profit Conditions

Repeating zero-profit condition (60) for Florida

$$\pi^{of}=p^u\left(Q^f+Q^{su}\right)q^f-C^f\left(q^f;\theta^f\right)-f^f=0$$

$$\pi^{of}=p^u\left(N^f q^f+N^s q^{su}\right)q^f-C^f\left(q^f;\theta^f\right)-f^f=0$$

FOC of equation (60) with respect to q^f:

$$\pi^{of}_{q^f}=q^f\frac{\partial p^u\left(N^f q^f+N^s q^{su}\right)}{\partial\left(N^f q^f+N^s q^{su}\right)}\underbrace{\frac{\partial\left(N^f q^f+N^s q^{su}\right)}{\partial N^f q^f}}_{=1}\underbrace{\frac{\partial N^f q^f}{\partial q^f}}_{=N^f}$$

$$+p^u\left(N^f q^f+N^s q^{su}\right)\underbrace{\frac{\partial q^f}{\partial q^f}}_{=1}-\frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}$$

$$\pi^{of}_{q^f}=q^f\frac{\partial p^u\left(N^f q^f+N^s q^{su}\right)}{\partial\left(N^f q^f+N^s q^{su}\right)}N^f+p^u\left(N^f q^f+N^s q^{su}\right)-\frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}<0$$

$$\pi^{of}_{q^f}=N^f q^f\frac{\partial p^u\left(N^f q^f+N^s q^{su}\right)}{\partial\left(N^f q^f+N^s q^{su}\right)}+p^u\left(N^f q^f+N^s q^{su}\right)-\frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}<0 \tag{77}$$

Since $\pi^f_{q^f}=q^f\frac{\partial p^u\left(Q^f+Q^{su}\right)}{\partial\left(Q^f+Q^{su}\right)}+p^u\left(Q^f+Q^{su}\right)-\frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}=0$, the above equation should be less than zero.

FOC of equation (60) with respect to q^{su}:

$$\pi^{of}_{q^{su}}=q^f\frac{\partial p^u\left(N^f q^f+N^s q^{su}\right)}{\partial\left(N^f q^f+N^s q^{su}\right)}\underbrace{\frac{\partial\left(N^f q^f+N^s q^{su}\right)}{\partial N^s q^{su}}}_{=1}\underbrace{\frac{\partial N^s q^{su}}{\partial q^{su}}}_{=N^s}+p^u\left(N^f q^f+N^s q^{su}\right)\underbrace{\frac{\partial q^f}{\partial q^{su}}}_{=0}$$

$$\pi^{of}_{q^{su}}=q^f\frac{\partial p^u\left(N^f q^f+N^s q^{su}\right)}{\partial\left(N^f q^f+N^s q^{su}\right)}N^s<0$$

$$\pi^{of}_{q^{su}}=N^s q^f\frac{\partial p^u\left(N^f q^f+N^s q^{su}\right)}{\partial\left(N^f q^f+N^s q^{su}\right)}<0 \tag{78}$$

FOC of equation (60) with respect to q^{se}:

$$\pi^{of}_{q^{se}}=0 \tag{79}$$

FOC of equation (60) with respect to N^f:

$$\pi^{of}_{N^f} = q^f \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^f q^f}}_{=1} \underbrace{\frac{\partial N^f q^f}{\partial N^f}}_{=q^f} + p^u\left(N^f q^f + N^s q^{su}\right) \underbrace{\frac{\partial q^f}{\partial N^f}}_{=0}$$

$$\pi^{of}_{N^f} = q^f \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} q^f$$

$$\pi^{of}_{N^f} = \left(q^f\right)^2 \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} < 0 \tag{80}$$

$$\pi^{of}_{N^s} = q^f \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^s q^{su}}}_{=1} \underbrace{\frac{\partial N^s q^{su}}{\partial N^s}}_{=q^{su}} + p^u\left(N^f q^f + N^s q^{su}\right) \underbrace{\frac{\partial q^f}{\partial N^s}}_{=0}$$

$$\pi^{of}_{N^s} = q^f \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} q^{su}$$

FOC of equation (60) with respect to N^s:

$$\pi^{of}_{N^s} = q^f q^{su} \frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} < 0 \tag{81}$$

Repeating zero-profit condition (61) for São Paulo:

$$\pi^{os} = \left(p^u\left(Q^f + Q^{su}\right) - \tau^u\right) q^{su} + \frac{p^e\left(Q^{se}\right)}{\left(1+\tau^e\right)} q^{se} - C^s\left(q^{su} + q^{se}; \theta^s\right) - t^u q^{su} - t^e q^{se} - f^s = 0$$

$$\begin{aligned}\pi^{os} = {} & \left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right) q^{su} + \frac{p^e\left(N^s q^{se}\right)}{\left(1+\tau^e\right)} q^{se} - C^s\left(q^{su} + q^{se}; \theta^s\right) - t^u q^{su} \\ & - t^e q^{se} - f^s = 0\end{aligned}$$

FOC of equation (61) with respect to q^f:

$$\pi^{os}_{q^f} = q^{su} \frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^f q^f}}_{=1} \underbrace{\frac{\partial N^f q^f}{\partial q^f}}_{=N^f}$$

$$\pi^{os}_{q^f} = q^{su} \frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} N^f < 0$$

$$\pi^{os}_{q^f} = N^f q^{su} \frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} < 0 \tag{82}$$

FOC of equation (61) with respect to q^{su}:

$$\begin{aligned}\pi^{os}_{q^{su}} = {} & q^{su} \frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} \underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^s q^{su}}}_{=1} \underbrace{\frac{\partial N^s q^{su}}{\partial q^{su}}}_{=N^s} \\ & + \left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right) \underbrace{\frac{\partial q^{su}}{\partial q^{su}}}_{=1} - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su}} - t^u\end{aligned}$$

$$\pi^{os}_{q^{su}} = q^{su}\frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} N^s + \left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su}} - t^u$$

$$\pi^{os}_{q^{su}} = N^s q^{su}\frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} + \left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su}} - t^u$$

$$\pi^{os}_{q^{su}} = N^s q^{su}\frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} + \left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su}} - t^u < 0 \tag{83}$$

Since $\pi^{s}_{q^{su}} = q^{su}\frac{\partial p^u\left(Q^f + Q^{su}\right)}{\partial\left(Q^f + Q^{su}\right)} + \left(p^u\left(Q^f + Q^{su}\right) - \tau^u\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{su}} - t^u = 0$, the above equation is negative.

FOC of equation (61) with respect to q^{se}:

$$\pi^{os}_{q^{se}} = \frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)}\underbrace{\frac{\partial\left(N^s q^{se}\right)}{\partial q^{se}}}_{= N^s} + \frac{p^e\left(N^s q^{se}\right)}{(1+\tau^e)}\underbrace{\frac{\partial q^{se}}{\partial q^{se}}}_{= 1} - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}} - t^e$$

$$\pi^{os}_{q^{se}} = \frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)} N^s + \frac{p^e\left(N^s q^{se}\right)}{(1+\tau^e)} - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}} - t^e$$

$$\pi^{os}_{q^{se}} = \frac{1}{(1+\tau^e)}\left(N^s q^{se}\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)} + p^e\left(N^s q^{se}\right)\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}} - t^e < 0 \tag{84}$$

Since $\pi^{s}_{q^{se}} = \frac{1}{(1+\tau^e)}\left(q^{se}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}} + p^e\left(Q^{se}\right)\right) - \frac{\partial C^s\left(q^{su} + q^{se}; \theta^s\right)}{\partial q^{se}} - t^e = 0$, the above equation is negative.

FOC of equation (61) with respect to N^f:

$$\pi^{os}_{N^f} = q^{su}\frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)}\underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^f q^f}}_{= 1}\underbrace{\frac{\partial N^f q^f}{\partial N^f}}_{= q^f}$$

$$\pi^{os}_{N^f} = q^{su}\frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} q^f$$

$$\pi^{os}_{N^f} = q^f q^{su}\frac{\partial p^u\left(N^f q^f + N^s q^{su}\right)}{\partial\left(N^f q^f + N^s q^{su}\right)} < 0 \tag{85}$$

FOC of equation (61) with respect to N^s:

$$\pi^{os}_{N^s} = q^{su}\frac{\partial\left(p^u\left(N^f q^f + N^s q^{su}\right) - \tau^u\right)}{\partial\left(N^f q^f + N^s q^{su}\right)}\underbrace{\frac{\partial\left(N^f q^f + N^s q^{su}\right)}{\partial N^s q^{su}}}_{= 1}\underbrace{\frac{\partial N^s q^{su}}{\partial N^s}}_{= q^{su}} + \frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(N^s q^{se}\right)}{\partial\left(N^s q^{se}\right)}\underbrace{\frac{\partial\left(N^s q^{se}\right)}{\partial N^s}}_{= q^{se}}$$

$$\pi^{os}_{N^s} = q^{su}\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}q^{su}+\frac{q^{se}}{(1+\tau^e)}\frac{\partial p^e\left(N^sq^{se}\right)}{\partial\left(N^sq^{se}\right)}q^{se}$$
$$\pi^{os}_{N^s} = \left(q^{su}\right)^2\frac{\partial\left(p^u\left(N^fq^f+N^sq^{su}\right)-\tau^u\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}+\frac{\left(q^{se}\right)^2}{(1+\tau^e)}\frac{\partial p^e\left(N^sq^{se}\right)}{\partial\left(N^sq^{se}\right)}$$
$$\pi^{os}_{N^s} = \left(q^{su}\right)^2\frac{\partial p^u\left(N^fq^f+N^sq^{su}\right)}{\partial\left(N^fq^f+N^sq^{su}\right)}+\frac{\left(q^{se}\right)^2}{(1+\tau^e)}\frac{\partial p^e\left(N^sq^{se}\right)}{\partial\left(N^sq^{se}\right)}<0 \tag{86}$$

The impact of a change in the tariff and productivity on the marginal change in profits is given by

$$\begin{aligned}
\pi^f_{q^f\tau^u} &= 0,\ \pi^f_{q^f\tau^e}=0,\ \pi^f_{q^f\theta^f}=-\frac{\partial^2C^f\left(q^f;\theta^f\right)}{\partial q^f\partial\theta^f}>0,\ \pi^f_{q^f\theta^s}=0\\
\pi^s_{q^{su}\tau^u} &= -1<0,\ \pi^s_{q^{su}\tau^e}=0,\ \pi^s_{q^{su}\theta^f}=0,\ \pi^s_{q^{su}\theta^s}=-\frac{\partial^2C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{su}\partial\theta^s}>0\\
\pi^s_{q^{se}\tau^u} &= 0,\ \pi^s_{q^{se}\tau^e}=-\frac{1}{(1+\tau^e)^2}\left(q^{se}\frac{\partial p^e\left(Q^{se}\right)}{\partial Q^{se}}+p^e\left(Q^{se}\right)\right)<0,\ \pi^s_{q^{se}\theta^f}=0,\\
\pi^s_{q^{se}\theta^s} &= -\frac{\partial^2C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial q^{se}\partial\theta^s}>0\\
\pi^{of}_{\tau^u} &= 0,\ \pi^{of}_{\tau^e}=0,\ \pi^{of}_{\theta^f}=-\frac{\partial C^f\left(q^f;\theta^f\right)}{\partial\theta^f}>0,\ \pi^{of}_{\theta^s}=0\\
\pi^{os}_{\tau^u} &= -q^{su}<0,\ \pi^{os}_{\tau^e}=-\frac{1}{(1+\tau^e)^2}p^e\left(Q^{se}\right)q^{se}<0,\ \pi^{os}_{\theta^f}=0,\\
\pi^{os}_{\theta^s} &= -\frac{\partial C^s\left(q^{su}+q^{se};\theta^s\right)}{\partial\theta^s}>0
\end{aligned}$$

Comparative Statics

Totally differentiating the FOCs yields a system of five equation, written in the form $Ax=d$ we get

$$\begin{bmatrix}
\pi^f_{q^fq^f} & \pi^f_{q^fq^{su}} & \pi^f_{q^fq^{se}} & \pi^f_{q^fN^f} & \pi^f_{q^fN^s}\\
\pi^s_{q^{su}q^f} & \pi^s_{q^{su}q^{su}} & \pi^s_{q^{su}q^{se}} & \pi^s_{q^{su}N^f} & \pi^s_{q^{su}N^s}\\
\pi^s_{q^{se}q^f} & \pi^s_{q^{se}q^{su}} & \pi^s_{q^{se}q^{se}} & \pi^s_{q^{se}N^f} & \pi^s_{q^{se}N^s}\\
\pi^{of}_{q^f} & \pi^{of}_{qsu} & \pi^{of}_{q^{se}} & \pi^{of}_{N^f} & \pi^{of}_{N^s}\\
\pi^{os}_{q^f} & \pi^{os}_{qsu} & \pi^{os}_{q^{se}} & \pi^{os}_{N^f} & \pi^{os}_{N^s}
\end{bmatrix}\begin{bmatrix} dq^f\\ dq^{su}\\ dq^{se}\\ dN^f\\ dN^s\end{bmatrix}=$$

$$-\begin{bmatrix} \pi^{f}_{q^f\tau^u}d\tau^u + \pi^{f}_{q^f\tau^e}d\tau^e + \pi^{f}_{q^f\theta^f}d\theta^f + \pi^{f}_{q^f\theta^s}d\theta^s \\ \pi^{s}_{q^{su}\tau^u}d\tau^u + \pi^{s}_{q^{su}\tau^e}d\tau^e + \pi^{s}_{q^{su}\theta^f}d\theta^f + \pi^{s}_{q^{su}\theta^s}d\theta^s \\ \pi^{s}_{q^{se}\tau^u}d\tau^u + \pi^{s}_{q^{se}\tau^e}d\tau^e + \pi^{s}_{q^{se}\theta^f}d\theta^f + \pi^{s}_{q^{se}\theta^s}d\theta^s \\ \pi^{of}_{\tau^u}d\tau^u + \pi^{of}_{\tau^e}d\tau^e + \pi^{of}_{\theta^f}d\theta^f + \pi^{of}_{\theta^s}d\theta^s \\ \pi^{os}_{\tau^u}d\tau^u + \pi^{os}_{\tau^e}d\tau^e + \pi^{os}_{\theta^f}d\theta^f + \pi^{os}_{\theta^s}d\theta^s \end{bmatrix}$$

Substituting the results of SOCs in the above system of equations, we get,

$$\begin{bmatrix} \pi^{f}_{q^fq^f} & \pi^{f}_{q^fq^{su}} & 0 & \pi^{f}_{q^fN^f} & \pi^{f}_{q^fN^s} \\ \pi^{s}_{q^{su}q^f} & \pi^{s}_{q^{su}q^{su}} & \pi^{s}_{q^{su}q^{se}} & \pi^{s}_{q^{su}N^f} & \pi^{s}_{q^{su}N^s} \\ 0 & \pi^{s}_{q^{se}q^{su}} & \pi^{s}_{q^{se}q^{se}} & 0 & \pi^{s}_{q^{se}N^s} \\ \pi^{of}_{q^f} & \pi^{of}_{q^{su}} & 0 & \pi^{of}_{N^f} & \pi^{of}_{N^s} \\ \pi^{os}_{q^f} & \pi^{os}_{qsu} & \pi^{os}_{q^{se}} & \pi^{os}_{N^f} & \pi^{os}_{N^s} \end{bmatrix} \begin{bmatrix} dq^f \\ dq^{su} \\ dq^{se} \\ dN^f \\ dN^s \end{bmatrix} = -\begin{bmatrix} \pi^{f}_{q^f\theta^f}d\theta^f \\ \pi^{s}_{q^{su}\tau^u}d\tau^u + \pi^{s}_{q^{su}\theta^s}d\theta^s \\ \pi^{s}_{q^{se}\tau^e}d\tau^e + \pi^{s}_{q^{se}\theta^s}d\theta^s \\ \pi^{of}_{\theta^f}d\theta^f \\ \pi^{os}_{\tau^u}d\tau^u + \pi^{os}_{\tau^e}d\tau^e + \pi^{os}_{\theta^s}d\theta^s \end{bmatrix}$$

We analyze the effect of a change in τ^u, τ^e, θ^f, and θ^s on q^f, q^{su}, q^{se}, N^f and N^s by applying Cramer's rule.

Determinant of matrix A:

$$\begin{aligned} \det(A) = {} & \pi^{f}_{q^fq^f}\pi^{os}_{q^{se}}\pi^{s}_{q^{se}N^s}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}N^f} + \pi^{of}_{N^f}\pi^{f}_{q^fq^f}\pi^{os}_{q^{se}}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}N^s} + \pi^{os}_{N^f}\pi^{f}_{q^fq^f}\pi^{s}_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}N^s} \\ & -\pi^{of}_{N^f}\pi^{f}_{q^fq^f}\pi^{s}_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}N^s} + \pi^{of}_{N^f}\pi^{f}_{q^fq^{su}}\pi^{os}_{q^{se}}\pi^{s}_{q^{se}N^s}\pi^{s}_{q^{su}q^f} + \pi^{of}_{N^f}\pi^{f}_{q^fN^s}\pi^{os}_{q^{se}}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}q^f} - \\ & \pi^{f}_{q^fN^f}\pi^{os}_{q^{se}}\pi^{s}_{q^{se}N^s}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}q^f} - \pi^{os}_{N^f}\pi^{f}_{q^fN^s}\pi^{s}_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}q^f} + \pi^{of}_{N^f}\pi^{f}_{q^fN^s}\pi^{s}_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}q^f} + \\ & \pi^{os}_{N^f}\pi^{f}_{q^fq^f}\pi^{s}_{q^{se}N^s}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}q^{se}} + \pi^{of}_{N^f}\pi^{f}_{q^fq^f}\pi^{s}_{q^{se}N^s}\pi^{of}_{q^{su}}\pi^{s}_{q^{su}q^{se}} - \pi^{of}_{N^f}\pi^{f}_{q^fq^f}\pi^{os}_{q^{se}}\pi^{s}_{q^{se}N^s}\pi^{s}_{q^{su}q^{su}} - \\ & \pi^{os}_{N^s}(\pi^{s}_{q^{se}q^{se}}(\pi^{of}_{N^f}\pi^{f}_{q^fq^{su}} - \pi^{f}_{q^fN^f}\pi^{of}_{q^{su}})\pi^{s}_{q^{su}q^f} + \pi^{f}_{q^fq^f}(\pi^{of}_{N^f}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}q^{se}} + \pi^{s}_{q^{se}q^{se}} \\ & (\pi^{of}_{q^{su}}\pi^{s}_{q^{su}N^f} - \pi^{of}_{N^f}\pi^{s}_{q^{su}q^{su}}))) + \pi^{of}_{N^s}((\pi^{os}_{N^f}\pi^{f}_{q^fq^{su}}\pi^{s}_{q^{se}q^{se}} + \pi^{f}_{q^fN^f}(\pi^{os}_{q^{se}}\pi^{s}_{q^{se}q^{su}} - \pi^{s}_{q^{se}q^{se}}\pi^{os}_{qsu}))\pi^{s}_{q^{su}q^f} \\ & + \pi^{f}_{q^fq^f}(-\pi^{os}_{q^{se}}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}N^f} + \pi^{os}_{N^f}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}q^{se}} + \pi^{s}_{q^{se}q^{se}}(\pi^{os}_{qsu}\pi^{s}_{q^{su}N^f} - \pi^{os}_{N^f}\pi^{s}_{q^{su}q^{su}}))) \\ & + \pi^{of}_{q^f}(\pi^{f}_{q^fq^{su}}(-\pi^{os}_{q^{se}}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}N^f} + \pi^{os}_{N^s}\pi^{s}_{q^{se}q^{se}}\pi^{s}_{q^{su}N^f} + \pi^{os}_{N^f}(-\pi^{s}_{q^{se}q^{se}}\pi^{s}_{q^{su}N^s} + \pi^{s}_{q^{se}N^s}\pi^{s}_{q^{su}q^{se}})) \\ & + \pi^{f}_{q^fN^s}(\pi^{os}_{q^{se}}\pi^{s}_{q^{su}q^{se}}\pi^{s}_{q^{su}N^f} - \pi^{os}_{N^f}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}q^{se}} + \pi^{s}_{q^{se}q^{se}}(-\pi^{os}_{qsu}\pi^{s}_{q^{su}N^f} + \pi^{os}_{N^f}\pi^{s}_{q^{su}q^{su}})) + \\ & \pi^{f}_{q^fN^f}((\pi^{os}_{N^s}\pi^{s}_{q^{se}q^{su}} - \pi^{s}_{q^{se}N^s}\pi^{os}_{qsu})\pi^{s}_{q^{su}q^{se}} + \pi^{s}_{q^{se}q^{se}}(\pi^{os}_{qsu}\pi^{s}_{q^{su}N^s} - \pi^{os}_{N^s}\pi^{s}_{q^{su}q^{su}} + \\ & \pi^{os}_{q^{se}}(-\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}N^s} + \pi^{s}_{q^{se}N^s}\pi^{s}_{q^{se}q^{su}}))) + \pi^{os}_{q^f}((\pi^{of}_{N^f}\pi^{f}_{q^fq^{su}} - \pi^{f}_{q^fN^f}\pi^{of}_{q^{su}})(\pi^{s}_{q^{se}q^{se}}\pi^{s}_{q^{su}N^s} - \\ & \pi^{s}_{q^{se}N^s}\pi^{s}_{q^{su}q^{se}}) + \pi^{f}_{q^fN^s}(\pi^{of}_{N^f}\pi^{s}_{q^{se}q^{su}}\pi^{s}_{q^{su}q^{se}} + \pi^{s}_{q^{se}q^{se}}(\pi^{of}_{q^{su}}\pi^{s}_{q^{su}N^f} - \pi^{of}_{N^f}\pi^{s}_{q^{su}q^{su}})) \end{aligned}$$

$$-\pi^{of}_{N^s}(\pi^f_{q^f q^{su}}\pi^s_{q^{se}q^{se}}\pi^s_{q^{su}N^f} + \pi^f_{q^f N^f}(\pi^s_{q^{se}q^{su}}\pi^s_{q^{su}q^{se}} - \pi^s_{q^{se}q^{se}}\pi^s_{q^{su}q^{su}}))).$$

The determinant of A is positive as shown by $|A| => 0$.

Change in q^f due to change in τ^u

$$\frac{dq^f}{d\tau^u} = \frac{1}{|A|}\,|A_{\tau^u}|$$

$$|A_{\tau^u}| = (-\pi^{of}_{N^f}\pi^f_{q^f q^{su}}\pi^{os}_{q^{se}}\pi^s_{q^{se}N^s}\pi^s_{q^{su}\tau^u} - \pi^{os}_{N^f}\pi^{of}_{N^s}\pi^f_{q^f q^{su}}\pi^s_{q^{se}q^{se}}\pi^s_{q^{su}\tau^u} + \pi^{of}_{N^f}\pi^{os}_{N^s}\pi^f_{q^f q^{su}}\pi^s_{q^{se}q^{se}}\pi^s_{q^{su}\tau^u}$$
$$-\pi^{of}_{N^s}\pi^f_{q^f N^f}\pi^{os}_{q^{se}}\pi^s_{q^{se}q^{su}}\pi^s_{q^{su}\tau^u} + \pi^{of}_{N^f}\pi^f_{q^f N^s}\pi^{os}_{q^{se}}\pi^s_{q^{se}q^{su}}\pi^s_{q^{su}\tau^u} + \pi^f_{q^f N^f}\pi^{os}_{q^{se}}\pi^s_{q^{se}N^s}\pi^{of}_{q^{su}}\pi^s_{q^{su}\tau^u}$$
$$-\pi^{os}_{N^s}\pi^f_{q^f N^f}\pi^s_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^s_{q^{su}\tau^u} + \pi^{os}_{N^f}\pi^f_{q^f N^s}\pi^s_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^s_{q^{su}\tau^u} + \pi^{of}_{N^s}\pi^f_{q^f N^f}\pi^s_{q^{se}q^{se}}\pi^{of}_{q^{su}}\pi^s_{q^{su}\tau^u}$$
$$-\pi^{of}_{N^f}\pi^f_{q^f N^s}\pi^{os}_{q^{su}}\pi^s_{q^{se}q^{se}}\pi^s_{q^{su}\tau^u} + \pi^{of}_{N^f}\pi^f_{q^f q^{su}}\pi^s_{q^{se}N^s}\pi^s_{q^{su}q^{se}}\pi^{os}_{\tau^u} + \pi^{of}_{N^s}\pi^f_{q^f N^f}\pi^s_{q^{se}q^{su}}\pi^s_{q^{su}q^{se}}\pi^{os}_{\tau^u}$$
$$-\pi^{of}_{N^f}\pi^f_{q^f N^s}\pi^s_{q^{se}q^{su}}\pi^s_{q^{su}q^{se}}\pi^{os}_{\tau^u} - \pi^f_{q^f N^f}\pi^s_{q^{se}N^s}\pi^{of}_{q^{su}}\pi^s_{q^{su}q^{se}}\pi^{os}_{\tau^u} - \pi^s_{q^{se}q^{se}}(-\pi^{of}_{N^s}\pi^f_{q^f q^{su}}\pi^s_{q^{su}N^f} +$$
$$\pi^f_{q^f N^s}\pi^{of}_{q^{su}}\pi^s_{q^{su}N^f} + \pi^{of}_{N^f}\pi^f_{q^f q^{su}}\pi^s_{q^{su}N^s} - \pi^f_{q^f N^f}\pi^{of}_{q^{su}}\pi^s_{q^{su}N^s} + \pi^{of}_{N^s}\pi^f_{q^f N^f}\pi^s_{q^{su}q^{su}} - \pi^{of}_{N^f}\pi^f_{q^f N^s}\pi^s_{q^{su}q^{su}})\pi^{os}_{\tau^u})$$

The sign of the above determinant and similarly, comparative static results of other variables are ambiguous because the different components are moving in different direction and hence the results are quantified numerically in the empirical analysis section.

Welfare Analysis of Tariff Changes and Changes in São Paulo Productivity

United States Welfare Analysis of a Reduction in the U.S. Tariff

The welfare function for the United States consists of profits, consumer surplus, and tariff revenues. But under free entry and exit, profits are zero.

$$W^u\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^u\left(Q^u\right)dQ^u - p^u\left(Q^u\right)Q^u\right\} + \tau^u Q^{su}$$

where consumer surplus, $CS = \left\{\int p^u\left(Q^u\right)dQ^u - p^u\left(Q^u\right)Q^u\right\}$ and tariff revenue, $TR = \tau^u Q^{su}$.

The change in consumer surplus with respect to a change in the U.S. tariff is:

$$\begin{aligned}\frac{dCS\left(\cdot\right)}{d\tau^u} &= p^u\left(Q^u\right)\frac{\partial Q^u}{\partial \tau^u} - Q^u\frac{\partial p^u}{\partial Q^u}\frac{\partial Q^u}{\partial \tau^u} - p^u\frac{\partial Q^u}{\partial \tau^u} \\ &= \left(-\frac{\partial p^u}{\partial Q^u}Q^u\right)\frac{\partial Q^u}{\partial \tau^u}.\end{aligned}$$

The change in tariff revenue with respect to a change in the U.S. tariff is:

$$\frac{dTR\left(\cdot\right)}{d\tau^u} = \tau^u\frac{\partial Q^{su}}{\partial \tau^u} + Q^{su}.$$

Therefore, we can express the total change in welfare as:

$$\begin{aligned}
\frac{dW^u(\cdot)}{d\tau^u} &= \frac{dCS(Q^u)}{d\tau^u} + \frac{dR(Q^u)}{d\tau^u} \\
&= \left(-\frac{\partial p^u}{\partial Q^u} Q^u\right) \frac{\partial Q^u}{\partial \tau^u} + \tau^u \frac{\partial Q^{su}}{\partial \tau^u} + Q^{su} \\
&= \underbrace{-\frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \tau^u} Q^u}_{\text{CS}(-)} + \underbrace{\underbrace{\frac{\partial Q^{su}}{\partial \tau^u} \tau^u}_{-} + \underbrace{Q^{su}}_{+}}_{\text{TR}(?)}
\end{aligned}$$

The above results show that the welfare could be positive or negative.

São Paulo Welfare Analysis of a Reduction in the U.S. Tariff

The welfare function for the São Paulo is:

$$W^s\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \pi^{os}\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = 0$$

because of no consumption of processed orange juice in Brazil.

European Welfare Analysis of a Reduction in the U.S. Tariff

Since European Union only consumes orange juice and collects tariff revenues, the European welfare is

$$W^e\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^e(Q^{se})\, dQ^{se} - p^e(Q^{se})\, Q^{se}\right\} + p^e(Q^{se})\, \tau^e Q^{se}$$

where consumer surplus, $CS = \left\{\int p^e(Q^{se})\, dQ^{se} - p^e(Q^{se})\, Q^{se}\right\}$ and tariff revenue, $TR = p^e(Q^{se})\, \tau^e Q^{se}$.

The change in European consumer surplus arising from a change in U.S. tariff is

$$\begin{aligned}
\frac{dCS(\cdot)}{d\tau^u} &= p^e(Q^{se}) \frac{\partial Q^{se}}{\partial \tau^u} - Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u} - p^e \frac{\partial Q^{se}}{\partial \tau^u} \\
&= -Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u}.
\end{aligned}$$

The change in European tariff revenue arising from a change in U.S. tariff is

$$\frac{dTR(\cdot)}{d\tau^u} = \tau^e Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u} + p^e(Q^{se})\, \tau^e \frac{\partial Q^{se}}{\partial \tau^u}.$$

The total change in the European welfare is expressed as:

$$\frac{dW^e(\cdot)}{d\tau^u} == \underbrace{-Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^u}}_{\text{CS}(+)} + \underbrace{\underbrace{\left(Q^{se}\frac{\partial p^e}{\partial Q^{se}} + p^e\right)}_{+}\underbrace{\tau^e\frac{\partial Q^{se}}{\partial \tau^u}}_{+}}_{\text{TR}(+)}$$

Thus, the above result shows that European welfare decreases as the United States reduces its tariff.

United States Welfare Analysis of a Reduction in the European Tariff

The welfare function for the United States consists of only consumer surplus and tariff revenues since profits are zero.

$$W^u\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^u(Q^u)\,dQ^u - p^u(Q^u)\,Q^u\right\} + \tau^u Q^{su}.$$

where consumer surplus, $CS = \left\{\int p^u(Q^u)\,dQ^u - p^u(Q^u)\,Q^u\right\}$ and tariff revenue, $\tau^u Q^{su}$.

The change in the U.S. consumer surplus with respect to a change in τ^e is:

$$\begin{aligned}\frac{dCS(\cdot)}{d\tau^e} &= p^u(Q^u)\frac{\partial Q^u}{\partial \tau^e} - Q^u\frac{\partial p^u}{\partial Q^u}\frac{\partial Q^u}{\partial \tau^e} - p^u\frac{\partial Q^u}{\partial \tau^e} \\ &= \left(-\frac{\partial p^u}{\partial Q^u}Q^u\right)\frac{\partial Q^u}{\partial \tau^e}.\end{aligned}$$

The change in the U.S. tariff revenue with respect to a change in τ^e is:

$$\frac{dTR(\cdot)}{d\tau^e} = \tau^u\frac{\partial Q^{su}}{\partial \tau^e} + 0.$$

Thus the total change in U.S. welfare with respect to τ^e is:

$$\begin{aligned}\frac{dW^u(\cdot)}{d\tau^e} &= \frac{dCS(Q^u)}{d\tau^e} + \frac{dTR(Q^u)}{d\tau^e} \\ &= \underbrace{\underbrace{-Q^u\frac{\partial p^u}{\partial Q^u}}_{+}\underbrace{\frac{\partial Q^u}{\partial \tau^e}}_{+}}_{\text{CS}(+)} + \underbrace{\tau^u\frac{\partial Q^{su}}{\partial \tau^e}}_{\text{TR}(-)}.\end{aligned}$$

The above results show that the U.S. welfare decreases as European Union reduces its tariff.

São Paulo Welfare Analysis of a Reduction in the European Tariff

The welfare function for the São Paulo is:

$$W^s\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \pi^{os}\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = 0$$

because of no consumption of processed orange juice in Brazil.

European Welfare Analysis of a Reduction in the European Tariff

Since European Union only consumes orange juice and collects tariff revenues, the European welfare is:

$$W^e\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^e\left(Q^{se}\right) dQ^{se} - p^e\left(Q^{se}\right) Q^{se}\right\} + p^e\left(Q^{se}\right)\tau^e Q^{se}$$

where consumer surplus, $CS = \left\{\int p^e\left(Q^{se}\right) dQ^{se} - p^e\left(Q^{se}\right) Q^{se}\right\}$ and tariff revenue, $TR = p^e\left(Q^{se}\right)\tau^e Q^{se}$.

Thus, the change in the European consumer surplus arising from a change in the European tariff is:

$$\begin{aligned}\frac{dCS(\cdot)}{d\tau^e} &= p^e\left(Q^{se}\right)\frac{\partial Q^{se}}{\partial \tau^e} - Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^e} - p^e\frac{\partial Q^{se}}{\partial \tau^e} \\ &= -Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^e}.\end{aligned}$$

The change in the European tariff revenues arising from a change in the European tariff is:

$$\frac{dTR(\cdot)}{d\tau^e} = \tau^e Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^e} + p^e\tau^e\frac{\partial Q^{se}}{\partial \tau^e} + p^e Q^{se}.$$

The total change in welfare is:

$$\frac{dW^e(\cdot)}{d\tau^e} = \underbrace{-Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \tau^e}}_{\text{CS}(-)} + \underbrace{\left(Q^{se}\frac{\partial p^e}{\partial Q^{se}} + p^e\right)\tau^e\frac{\partial Q^{se}}{\partial \tau^e} + p^e Q^{se}}_{\text{TR}(?)}$$

As European Union reduces its tariff its consumer surplus will increase but tariff revenues will go down, and the net welfare change could be positive or negative.

United States Welfare Analysis of a Reduction in the U.S. and European Tariff

The welfare function for the United States consists of profits, consumer surplus, and tariff revenues. But under free entry and exit, profits are zero.

$$W^u\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^u\left(Q^u\right) dQ^u - p^u\left(Q^u\right) Q^u\right\} + \tau^u Q^{su}$$

where consumer surplus, $CS = \left\{\int p^u\left(Q^u\right) dQ^u - p^u\left(Q^u\right) Q^u\right\}$ and tariff revenue, $\tau^u Q^{su}$.

The change in consumer surplus with respect to a change in the U.S. and European Union tariff is:

$$dCS(\cdot) = \frac{\partial CS}{\partial \tau^u} d\tau^u + \frac{\partial CS}{\partial \tau^e} d\tau^e$$

$$\begin{aligned} dCS(\cdot) &= \left(p^u (Q^u) \frac{\partial Q^u}{\partial \tau^u} - Q^u \frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \tau^u} - p^u \frac{\partial Q^u}{\partial \tau^u} \right) d\tau^u \\ &\quad + \left(p^u (Q^u) \frac{\partial Q^u}{\partial \tau^e} - Q^u \frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \tau^e} - p^u \frac{\partial Q^u}{\partial \tau^e} \right) d\tau^e \\ &= \left(p^u - \frac{\partial p^u}{\partial Q^u} Q^u - p^u \right) \frac{\partial Q^u}{\partial \tau^u} d\tau^u + \left(p^u - \frac{\partial p^u}{\partial Q^u} Q^u - p^u \right) \frac{\partial Q^u}{\partial \tau^e} d\tau^e \\ &= \left(-\frac{\partial p^u}{\partial Q^u} Q^u \right) \frac{\partial Q^u}{\partial \tau^u} d\tau^u + \left(-\frac{\partial p^u}{\partial Q^u} Q^u \right) \frac{\partial Q^u}{\partial \tau^e} d\tau^e. \end{aligned}$$

The change in tariff revenue with respect to a change in the U.S. and European Union tariff is:

$$dTR(\cdot) = \frac{\partial TR}{\partial \tau^u} d\tau^u + \frac{\partial TR}{\partial \tau^e} d\tau^e$$

$$dTR(\cdot) = \left(\tau^u \frac{\partial Q^{su}}{\partial \tau^u} + Q^{su} \right) d\tau^u + \left(\tau^u \frac{\partial Q^{su}}{\partial \tau^e} \right) d\tau^e.$$

Therefore, we can express the total change in welfare as:

$$\begin{aligned} dW^u(\cdot) &= dCS(\cdot) + dTR(\cdot) \\ &= \underbrace{\underbrace{-\frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \tau^u} Q^u}_{-} + \underbrace{\frac{\partial Q^{su}}{\partial \tau^u} \tau^u}_{-}}_{\text{CS}(-)} + \underbrace{\underbrace{Q^{su}}_{+} \underbrace{\underbrace{-Q^u \frac{\partial p^u}{\partial Q^u}}_{+} \underbrace{\frac{\partial Q^u}{\partial \tau^e}}_{+}}_{+} + \underbrace{\tau^u \frac{\partial Q^{su}}{\partial \tau^e}}_{+}}_{\text{TR}(-)}. \end{aligned}$$

The above results show that the welfare could be positive or negative.

São Paulo Welfare Analysis of a Reduction in the U.S. and European Tariff

The welfare function for the São Paulo is:

$$W^s \left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s \right) = \pi^{os} \left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s \right) = 0$$

because of no consumption of processed orange juice in Brazil.

European Welfare Analysis for a Reduction in the U.S. and European Tariff

Since European Union only consumes orange juice and collects tariff revenues, the European welfare is

$$W^e\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^e\left(Q^{se}\right) dQ^{se} - p^e\left(Q^{se}\right) Q^{se}\right\} + p^e\left(Q^{se}\right) \tau^e Q^{se}$$

where consumer surplus, $CS = \left\{\int p^e\left(Q^{se}\right) dQ^{se} - p^e\left(Q^{se}\right) Q^{se}\right\}$ and tariff revenue, $TR = p^e\left(Q^{se}\right) \tau^e Q^{se}$.

The change in European consumer surplus arising from a change in U.S. and European tariff is

$$\begin{aligned} dCS\left(\cdot\right) &= \left(p^e\left(Q^{se}\right) \frac{\partial Q^{se}}{\partial \tau^u} - Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u} - p^e \frac{\partial Q^{se}}{\partial \tau^u}\right) d\tau^u \\ &\quad + \left(p^e\left(Q^{se}\right) \frac{\partial Q^{se}}{\partial \tau^e} - Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^e} - p^e \frac{\partial Q^{se}}{\partial \tau^e}\right) d\tau^e \\ &= -\left(Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u}\right) d\tau^u - \left(Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^e}\right) d\tau^e. \end{aligned}$$

The change in European tariff revenue arising from a change in U.S. and European tariff is

$$dTR\left(\cdot\right) = \left(\tau^e Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u} + p^e\left(Q^{se}\right) \tau^e \frac{\partial Q^{se}}{\partial \tau^u}\right) d\tau^u + \left(\tau^e Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^e} + p^e \tau^e \frac{\partial Q^{se}}{\partial \tau^e} + p^e Q^{se}\right) d\tau^e.$$

The total change in the European welfare is expressed as:

$$dW^e\left(Q^{se}; \tau^e, \tau^u\right) = \underbrace{-Q^{se} \frac{\partial p^e}{\partial Q^{se}} \frac{\partial Q^{se}}{\partial \tau^u}}_{\text{CS}(+)} + \underbrace{\underbrace{\left(Q^{se} \frac{\partial p^e}{\partial Q^{se}} + p^e\right)}_{+} \underbrace{\tau^e \frac{\partial Q^{se}}{\partial \tau^u}}_{+}}_{\text{TR}(+)}.$$

Thus, the above result shows that European welfare decreases as the United States and European Union concurrently reduces its tariff.

United States Welfare Analysis of an increase in the São Paulo Productivity (Change in θ^s)

The welfare function for the United States consists of profits, consumer surplus, and tariff revenues. But under free entry and exit, profits are zero.

$$W^u\left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s\right) = \left\{\int p^u\left(Q^u\right) dQ^u - p^u\left(Q^u\right) Q^u\right\} + \tau^u Q^{su}$$

where consumer surplus, $CS = \left\{ \int p^u (Q^u)\, dQ^u - p^u (Q^u)\, Q^u \right\}$ and tariff revenue, $\tau^u Q^{su}$.

The change in consumer surplus with respect to a change in the São Paulo productivity is:

$$\begin{aligned} \frac{dCS(\cdot)}{d\theta^s} &= p^u (Q^u) \frac{\partial Q^u}{\partial \theta^s} - Q^u \frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \theta^s} - p^u \frac{\partial Q^u}{\partial \theta^s} \\ &= \left(-\frac{\partial p^u}{\partial Q^u} Q^u \right) \frac{\partial Q^u}{\partial \theta^s}. \end{aligned}$$

The change in tariff revenue with respect to a change in the São Paulo productivity is:

$$\begin{aligned} \frac{dTR(\cdot)}{d\theta^s} &= \frac{d(Q^{su}\tau^u)}{d\theta^s} \\ \frac{dTR(\cdot)}{d\theta^s} &= \tau^u \frac{\partial Q^{su}}{\partial \theta^s} \end{aligned}$$

Therefore, we can express the total change in welfare as:

$$\begin{aligned} \frac{dW^u(\cdot)}{d\theta^s} &= \frac{dCS(Q^u)}{d\theta^s} + \frac{dR(Q^u)}{d\theta^s} \\ &= \underbrace{-\frac{\partial p^u}{\partial Q^u} \frac{\partial Q^u}{\partial \theta^s} Q^u}_{\text{CS}(-)} + \underbrace{\tau^u \frac{\partial Q^{su}}{\partial \theta^s}}_{\text{TR}(-)}. \end{aligned}$$

The above results show that the welfare would be positive.

São Paulo Welfare Analysis of an increase in the São Paulo productivity

The welfare function for the São Paulo is:

$$W^s \left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s \right) = \pi^{os} \left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s \right) = 0$$

because of zero consumption of processed orange juice in Brazil.

European Welfare Analysis of an increase in the São Paulo productivity

Since European Union only consumes orange juice and collects tariff revenues, the European welfare is

$$W^e \left(Q^u, Q^{su}, Q^{se}, N^f, N^s; \tau^u, \tau^e, \theta^f, \theta^s \right) = \left\{ \int p^e (Q^{se})\, dQ^{se} - p^e (Q^{se})\, Q^{se} \right\} + p^e (Q^{se})\, \tau^e Q^{se}$$

where consumer surplus, $CS = \left\{ \int p^e (Q^{se})\, dQ^{se} - p^e (Q^{se})\, Q^{se} \right\}$ and tariff revenue, $TR = p^e (Q^{se})\, \tau^e Q^{se}$.

The change in European consumer surplus arising from a change in São Paulo productivity is

$$\begin{aligned}\frac{dCS(\cdot)}{d\theta^s} &= p^e(Q^{se})\frac{\partial Q^{se}}{\partial \theta^s} - Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \theta^s} - p^e\frac{\partial Q^{se}}{\partial \theta^s} \\ &= -Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \theta^s}.\end{aligned}$$

The change in European tariff revenue arising from a change in São Paulo productivity is

$$\begin{aligned}\frac{dTR(\cdot)}{d\theta^s} &= \tau^e Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \theta^s} + p^e(Q^{se})\tau^e\frac{\partial Q^{se}}{\partial \theta^s}. \\ &= +\underbrace{\tau^e Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \theta^s}}_{-} + \underbrace{p^e\tau^e\frac{\partial Q^{se}}{\partial \theta^s}}_{+}\end{aligned}$$

The total change in the European welfare is expressed as:

$$\begin{aligned}\frac{dW^e(\cdot)}{d\theta^s} &= \frac{dCS(Q^{se};\tau^e,\tau^u)}{d\theta^s} + \frac{dTR(Q^{se};\tau^e,\tau^u,\theta^s)}{d\theta^s} \\ &= \underbrace{-Q^{se}\frac{\partial p^e}{\partial Q^{se}}\frac{\partial Q^{se}}{\partial \theta^s}}_{\text{CS}(-)} + \underbrace{\left(Q^{se}\frac{\partial p^e}{\partial Q^{se}} + p^e\right)\tau^e\frac{\partial Q^{se}}{\partial \theta^s}}_{\text{TR}(-)}.\end{aligned}$$

Thus, the above result shows that European welfare increases as the São Paulo productivity increases.

Empirical Model and Analysis

Simulation

Supply relations

Firm-level supply relations

Florida:

$$p^u\left(Q^f + Q^{su}\right) = \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f} + \left(\psi^f\right)(\xi^u)\,p^u\left(Q^f + Q^{su}\right) \tag{87}$$

São Paulo to U.S.:

$$p^u\left(Q^f + Q^{su}\right) = \frac{\partial C^s\left(q^{su} + q^{se};\theta^s\right)}{\partial q^{su}} + t^u + (\psi^{su})(\xi^u)\,p^u\left(Q^f + Q^{su}\right) + \tau^u \tag{88}$$

São Paulo to EU:

$$p^e(Q^{se}) = (1+\tau^e)\left(\frac{\partial C^s\left(q^{su} + q^{se};\theta^s\right)}{\partial q^{se}} + t^e\right) + (\psi^{se})(\xi^e)\,p^e(Q^{se}) \tag{89}$$

The firm-level marginal cost functions are given by

Florida

$$mc^f = \frac{\partial C^f}{\partial q^f} = \gamma_0^f + \gamma_1^f q^f \tag{90}$$

São Paulo to the United States

$$mc^s = \frac{\partial C^s}{\partial q^{su}} = \gamma_0^s + \gamma_1^s \left(q^{su} + q^{se}\right) + t^u \tag{91}$$

São Paulo to the European Union

$$mc^s = \frac{\partial C^s}{\partial q^{se}} = \gamma_0^s + \gamma_1^s \left(q^{su} + q^{se}\right) + t^e \tag{92}$$

Substituting the above marginal cost functions into the firm-level supply relations

$p^u\left(Q^f + Q^{su}\right) = \gamma_0^f + \gamma_1^f q^f + \left(\psi^f\right)\left(\xi^u\right) p^u\left(Q^f + Q^{su}\right)$ Florida supply to U.S.

$p^u\left(Q^f + Q^{su}\right) = \gamma_0^s + \gamma_1^s\left(q^{su} + q^{se}\right) + t^u + \left(\psi^{su}\right)\left(\xi^u\right) p^u\left(Q^f + Q^{su}\right) + \tau^u$ São Paulo supply to U.S.

$p^e\left(Q^{se}\right) = \left(1 + \tau^e\right)\left(\gamma_0^s + \gamma_1^s\left(q^{su} + q^{se}\right) + t^e\right) + \left(\psi^{se}\right)\left(\xi^e\right) p^e\left(Q^{se}\right)$ São Paulo supply to European Union

Aggregate supply relations,

$p^u\left(Q^f + Q^{su}\right) = \gamma_0^f + \gamma_1^f Q^f + \left(\psi^f\right)\left(\xi^u\right) p^u\left(Q^f + Q^{su}\right)$ Florida supply to U.S.

$p^u\left(Q^f + Q^{su}\right) = \gamma_0^s + \gamma_1^s\left(Q^{su} + Q^{se}\right) + t^u + \left(\psi^{su}\right)\left(\xi^u\right) p^u\left(Q^f + Q^{su}\right) + \tau^u$ São Paulo supply to U.S.

$p^e\left(Q^{se}\right) = \left(1 + \tau^e\right)\left(\gamma_0^s + \gamma_1^s\left(Q^{su} + Q^{se}\right) + t^e\right) + \left(\psi^{se}\right)\left(\xi^e\right) p^e\left(Q^{se}\right)$ São Paulo supply to European Union

Rewriting the aggregate quantities in the above supply relations,

Florida supply to the United States

$$p^u\left(Q^f + Q^{su}\right) = \gamma_0^f + \gamma_1^f N^f q^f + \left(\psi^f\right)\left(\xi^u\right) p^u\left(Q^f + Q^{su}\right) \tag{93}$$

São Paulo supply to the United States

$$p^u\left(Q^f + Q^{su}\right) = \gamma_0^s + \gamma_1^s\left(N^s q^{su} + N^s q^{se}\right) + t^u + \left(\psi^{su}\right)\left(\xi^u\right) p^u\left(Q^f + Q^{su}\right) + \tau^u \tag{94}$$

São Paulo supply to the European Union

$$p^e\left(Q^{se}\right) = \left(1 + \tau^e\right)\left(\gamma_0^s + \gamma_1^s\left(N^s q^{su} + N^s q^{se}\right) + t^e\right) + \left(\psi^{se}\right)\left(\xi^e\right) p^e\left(Q^{se}\right) \tag{95}$$

Aggregate Demand Functions

U.S. Demand

$$p^u = \delta_0^u + \delta_1^u \left(Q^f + Q^{su}\right) \tag{96}$$

EU Demand

$$p^e = \delta_0^e + \delta_1^e Q^{se} \tag{97}$$

Cost functions

Florida:

$mc^f = \beta_1 + \beta_2 \left(Q^f\right)$ Florida marginal cost

Firm level total Cost:

$tc^f = tvc^f + f^f$

$tc^f = \left(\beta_1 + \beta_2 \left(Q^f\right)\right) q^f + f^f$

$tc^f = \left(\beta_1 + \beta_2 q^f N^f\right) q^f + f^f$

Industry level Total cost for Florida:

$TC^f = TVC^f + F^f$ where F^f is industry level total fixed cost

$$TC^f = \beta_1 \left(q^f N^f\right) + \frac{\beta_2}{2} \left(q^f N^f\right)^2 + F^f \tag{98}$$

São Paulo:

Firm level total cost:

$mc^s = \beta_1 + \beta_2 (q^{su} N^s + q^{se} N^s)$

Firm level total cost:

$tc^s = tvc^s + f^s$

$tc^s = [(\beta_1 + \beta_2 \left(q^{su} N^s + q^{se} N^s\right)) \left(q^{su} + q^{se}\right)] + f^f$

Industry level Total Cost:

Industry level Total Cost for São Paulo:

$TC^s = TVC^s + F^s$ where F^s is industry level total fixed cost

São Paulo to U.S.:

Integrating marginal cost with respect to $q^{su} N^s$

$\int [\beta_1 + \beta_2 (q^{su}N^s + q^{se}N^s)]\, d\,(q^{su}N^s)$

$\int [\beta_1 + \beta_2 q^{su}N^s + \beta_2 q^{se}N^s]\, d\,(q^{su}N^s) =$

$\beta_1 q^{su}N^s + \frac{\beta_2}{2}\left(q^{su}N^s\right)^2 + \beta_2\left(q^{se}N^s\right)\left(q^{su}N^s\right) + C^1$

São Paulo to EU:

Integrating marginal cost with respect to $q^{se}N^s$

$\int [\beta_1 + \beta_2 (q^{su}N^s + q^{se}N^s)]\, d\,(q^{se}N^s)$

$\int [\beta_1 + \beta_2 q^{su}N^s + \beta_2 q^{se}N^s]\, d\,(q^{se}N^s) =$

$\beta_1\left(q^{se}N^s\right) + \beta_2\left(q^{su}N^s\right)\left(q^{se}N^s\right) + \frac{\beta_2}{2}\left(q^{se}N^s\right)^2 + C^1$

Summing up the two, we get

$\beta_1 q^{su}N^s + \frac{\beta_2}{2}\left(q^{su}N^s\right)^2 + \beta_2\left(q^{se}N^s\right)\left(q^{su}N^s\right) + \beta_1\left(q^{se}N^s\right)$
$+\frac{\beta_2}{2}\left(q^{se}N^s\right)^2 + \beta_2\left(q^{su}N^s\right)\left(q^{se}N^s\right) + \tilde{C}$

$$\begin{aligned} TC^s = \beta_1 q^{su}N^s + \frac{\beta_2}{2}\left(q^{su}N^s\right)^2 + \beta_2\left(q^{se}N^s\right)\left(q^{su}N^s\right) + \\ \beta_1\left(q^{se}N^s\right) + \frac{\beta_2}{2}\left(q^{se}N^s\right)^2 + \beta_2\left(q^{su}N^s\right)\left(q^{se}N^s\right) + F^s \end{aligned} \tag{99}$$

where the integration constant $\tilde{C} = F^s$ is the fixed cost.

Calibration of Cost Parameters

Florida

$p^u\left(Q^f + Q^{su}\right)N^f = \frac{\partial C^f\left(q^f;\theta^f\right)}{\partial q^f}N^f + \left(\psi^f\right)\left(\xi^u\right)p^u\left(Q^f + Q^{su}\right)N^f$

$p^u N^f = \left(\beta_0^f + \beta_1^f Q^f\right)N^f + \psi^f \xi^u p^u N^f$

$p^u N^f = \left(\beta_0^f + \beta_1^f Q^f\right)N^f + \psi^f \alpha_1^u\left(Q^f + Q^{su}\right)N^f$

$p^u N^f = \beta_0^f N^f + \beta_1^f Q^f N^f + \psi^f \alpha_1^u\left(q^f N^f + q^{su}N^s\right)N^f$

We know N^f, $q^f N^f$, p^u, α_1^u, ψ^f, ε_{fl}^s

Getting β_1^f

$\varepsilon_{fl}^s = \frac{\partial p^u}{\partial q^f N^f}\frac{q^f N^f}{p^u}$

$p^u N^f = \beta_0^f N^f + \beta_1^f Q^f N^f + \psi^f \alpha_1^u\left(q^f N^f + q^{su}N^s\right)N^f$

$p^u N^f = \beta_0^f N^f + \beta_1^f\left(q^f N^f\right)N^f + \psi^f \alpha_1^u\left(q^f N^f + q^{su}N^s\right)N^f$

$p^u = \beta_0^f + \beta_1^f q^f N^f + \psi^f \alpha_1^u\left(q^f N^f + q^{su}N^s\right)$

$$\frac{\partial p^u}{\partial q^f N^f} = \beta_1^f + \psi^f \alpha_1^u$$

$$\varepsilon_{fl}^s = \left(\beta_1^f + \psi^f \alpha_1^u\right) \frac{q^f N^f}{p^u} = \left(\beta_1^f N^f + N^f \psi^f \alpha_1^u\right) \frac{q^f}{p^u}$$

$$\varepsilon_{fl}^s \frac{p^u}{q^f} = \beta_1^f N^f + N^f \psi^f \alpha_1^u$$

$$\beta_1^f = \varepsilon_{fl}^s \frac{p^u}{q^f N^f} - \psi^f \alpha_1^u$$

Getting β_0^f

$$p^u N^f = \beta_0^f N^f + \beta_1^f q^f N^f + \psi^f \alpha_1^u \left(q^f N^f + q^{su} N^s\right) N^f$$

$$p^u N^f - \beta_1^f \left(q^f N^f\right) N^f - \psi^f \alpha_1^u \left(q^f N^f + q^{su} N^s\right) N^f = \beta_0^f N^f$$

$$\beta_0^f = p^u - \beta_1^f \left(q^f N^f\right) - \psi^f \alpha_1^u \left(q^f N^f + q^{su} N^s\right)$$

Redefining Zero-Profit Conditions

With the firm-level specific cost functions derived above, the two zero-profit conditions are redefined as

$$\pi^{of} = p^u(q^f) - \left(\gamma_0^f + \frac{\gamma_1^f}{2} q^f\right) q^f - f^f \tag{100}$$

$$\begin{aligned} \pi^{os} = \left(p^u - \tau^u\right) q^{su} + \tfrac{p^e}{(1+\tau^e)} \left(q^{se}\right) \\ -(\gamma_0^s q^{su} + \tfrac{\gamma_1^s}{2} \left(q^{su}\right)^2 + 2 \left(q^{su}\right) \left(q^{se}\right) + \gamma_0^s q^{se} \\ + \tfrac{\gamma_1^s}{2} \left(q^{se}\right)^2 + \gamma_2^s t^u q^{su} + \gamma_3^s t^e q^{se} + f^s) \end{aligned} \tag{101}$$

Final System of Equations for Simulation

Florida supply to the United States:

$$p^u \left(Q^f + Q^{su}\right) = \gamma_0^f + \gamma_1^f N^f q^f + \left(\psi^f\right) \left(\xi^u\right) p^u \left(Q^f + Q^{su}\right)$$

São Paulo supply to the United States:

$$p^u \left(Q^f + Q^{su}\right) = \gamma_0^s + \gamma_1^s \left(N^s q^{su} + N^s q^{se}\right) + t^u + \left(\psi^{su}\right) \left(\xi^u\right) p^u \left(Q^f + Q^{su}\right) + \tau^u$$

São Paulo supply to the European Union:

$$p^e \left(Q^{se}\right) = \left(1 + \tau^e\right) \left(\gamma_0^s + \gamma_1^s \left(N^s q^{su} + N^s q^{se}\right) + t^e\right) + \left(\psi^{se}\right) \left(\xi^e\right) p^e \left(Q^{se}\right)$$

U.S. Demand:

$$p^u = \delta_0^u + \delta_1^u \left(Q^f + Q^{su}\right)$$

EU Demand:

$$p^e = \delta_0^e + \delta_1^e Q^{se}$$

ZPC for Florida:

$$\pi^{of} = p^u(q^f) - \left(\gamma_0^f + \frac{\gamma_1^f}{2} q^f\right) q^f - f^f$$

ZPC for São Paulo:

$$\pi^{os} = \left(p^u - \tau^u\right) q^{su} + \tfrac{p^e}{(1+\tau^e)} \left(q^{se}\right)$$
$$-\big(\gamma_0^s q^{su} + \tfrac{\gamma_1^s}{2} \left(q^{su}\right)^2 + 2\gamma_1^s \left(q^{su}\right) \left(q^{se}\right) + \gamma_0^s q^{se}$$
$$+\tfrac{\gamma_1^s}{2} \left(q^{se}\right)^2 + t^u q^{su} + t^e q^{se} + f^s\big)$$

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