NON-TARIFF BARRIERS AND TECHNOLOGY:

TRADE AND WELFARE IMPLICATIONS

By

LIA NOGUEIRA

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of LIA NOGUEIRA find it satisfactory and recommend that it be accepted.

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Co-Chair

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Co-Chair

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TRADE AND WELFARE IMPLICATIONS

Abstract

by Lia Nogueira, Ph.D.
Washington State University
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Co-Chairs: Hayley H. Chouinard and Thomas L. Marsh

This dissertation examines trade and welfare issues for non-tariff barriers and technology. We examine trade and welfare effects of: Sanitary and Phytosanitary (SPS) barriers to trade for Washington apples; Washington State University (WSU) wheat breeding programs and technology; and Foot-and-Mouth disease (FMD) outbreak for the Mexican cattle industry.

In the first article we characterize a full export model to estimate the effects of changing SPS barriers to trade on Washington State apples in China, India, Mexico and Taiwan. We use the SPS cost elasticities obtained from the export supply equations in revenue and surplus simulations. Our results provide promising information to Washington State apple producers. Exports to Mexico and Taiwan may increase significantly if SPS barriers decrease. We confirm China as an attractive market, regardless of SPS barriers to trade. Although exports to India may decrease if SPS barriers are enforced, the loss may not be large.

In the second article we calculate the welfare effects of the WSU wheat breeding programs and technology for producers and consumers in Washington State, Oregon, Idaho, the United States and the rest of the world. We draw insights about the effects of cutting edge processes such as DNA fingerprinting in wheat breeding research. We develop a partial equilibrium multi-region trade model for wheat that provides consumer, producer and total

surplus for each wheat class and region. Our results provide evidence suggesting that WSU wheat breeding programs have increased welfare in Washington State, in the United States and the rest of the world.

The objective of the third article is to analyze the effects on trade of a hypothetical FMD outbreak in the Mexican cattle industry. We simulate the consequences of an FMD outbreak under different mitigation scenarios. This study analyzes a relevant policy issue for the Mexican cattle industry. It is important for policy makers to understand the potential impacts of an FMD outbreak and the consequences of the different mitigation policies. Our results provide evidence suggesting the potential gains due to increased traceability and depopulation of latent infectious herds. However, it is important to consider the cost of implementing the necessary measures.

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Dedication

To my parents, whose love and support allowed me

to successfully accomplish my graduate studies.

To Cory, without whom I would not have

been able to get through this journey.

CHAPTER ONE

INTRODUCTION

This dissertation examines trade and welfare issues for non-tariff barriers and technology. We specifically examine trade and welfare effects of: Sanitary and Phytosanitary (SPS) barriers to trade for Washington apples in the first article; Washington State University (WSU) wheat breeding programs and technology in the second article; and Foot-and-Mouth disease (FMD) outbreak for the Mexican cattle industry in the third article.

The first article (chapter 2) provides an economic analysis of SPS barriers to trade. The Sanitary and Phytosanitary Measures Agreement of the World Trade Organization (WTO) allows its members to set standards on food products to protect domestic consumers. In practice, SPS barriers take the form of import standards or regulations that reflect the country's concern for SPS issues that could harm domestic production. Specifically, SPS barriers related to fire blight, codling moth, apple maggot and other pests limit or prohibit US apple exports to some countries, as well as impose additional costs on US apple producers and exporters. SPS barriers may also reduce the flow of apples into a country by imposing quarantine restrictions that delay shipments. Many argue SPS requirements restrict exports beyond what scientists consider necessary to protect the domestic product, and reducing SPS barriers will decrease costs to producers and increase trade.

We examine the effect of SPS barriers to trade imposed by China, India, Mexico and Taiwan on the Washington State apple industry. Specifically, we address the effects of changing the level of SPS barriers to trade on the revenue received by Washington State producers, and the economic surplus of importers and exporters. We estimate the complete system of equations that characterize all stages of the export model, and we incorporate an estimate of the cost of complying with the SPS regulations. This study complements the literature by including a direct estimate of the SPS compliance costs, by analyzing countries not thoroughly studied previously and by estimating price elasticities while including SPS costs in the model. Then, we estimate export quantity changes for Washington State apples given specific changes on SPS costs. This allows us to calculate the associated revenue changes for Washington producers with different SPS costs. Furthermore, we estimate welfare changes by calculating changes in importers' and exporters' surplus.

Our results yield estimates to provide policy recommendations that can be used by the industry to argue for the reduction of SPS barriers in other countries. Specifically, our results bring some promising information to the Washington State apple industry. We confirm China as an attractive market. Exports to Mexico and Taiwan may increase greatly if SPS barriers decrease. Even though exports to India may decrease if SPS barriers are enforced, the loss may not be large. In general, we provide further evidence of the potential gains for producers, exporters and importers if SPS barriers decrease.

In the second article (chapter 3), we calculate the welfare effects of the WSU wheat breeding programs and technology for producers and consumers in Washington State, Oregon, Idaho, the United States and the rest of the world. Welfare implications of wheat breeding programs and technology are important and relevant concerns for associated interest groups and the public in general. Due to favorable growing conditions soft white wheat is primarily grown in Eastern Washington. In Western Washington higher value crops are planted due to longer growing seasons, more heat units, and access to irrigation. Wheat varieties in Eastern

Washington are always being adapted to counteract specific issues that affect producers yield such as funguses and insects, as well as to meet producer demand for higher yielding varieties.

In addition to helping producers, these new varieties should also maintain or improve consumer desired characteristics. Thus, wheat breeding programs are important to both producers and consumers. However, it is not always easy to justify increased expenditure in wheat breeding research because of the long period of time from the beginning of the trials to the adoption of these varieties by growers, and the fact that growers do not buy seed every year, but save some of the harvested grain to plant the following year or years.

The main objective of this study is to calculate the welfare effects of the WSU wheat breeding programs and technology for producers and consumers in Washington State, Oregon, Idaho, the United States and the rest of the world. We also draw insights about the effects of cutting edge processes such as DNA fingerprinting in wheat breeding research. We develop a partial equilibrium multi-region trade model for wheat that provides consumer, producer and total surplus for each wheat class and region given a shift in the supply curve due to WSU wheat breeding programs. Using this model we analyze the effects of a research-induced supply shift on consumer, producer and total surplus for each wheat class, and region, including spillover effects to Oregon and Idaho, where producers use some of the varieties developed at WSU. Furthermore, we simulate the potential effects of the use of new technology like DNA fingerprinting in reducing costs and providing price premiums due to certificate of origin. To the best of our knowledge, this is the first study to incorporate the different wheat classes and the corresponding regions into the trade model.

Our results provide evidence suggesting that WSU wheat breeding programs have increased welfare in Washington State, in the United States and the rest of the world. Most of the welfare increases occur in Washington State, with producers being the main beneficiaries. Regarding DNA fingerprinting, our results suggest that it is an attractive technology that can potentially provide great surplus increases for producers in Washington.

The third article (chapter 4) analyzes the effects on trade (domestic and international) of a hypothetical FMD outbreak in the Mexican cattle industry, as well as producer and consumer responses. Outbreaks of FMD are important economic events, restricting trade world wide. The effects of FMD can be extremely detrimental to a country. Trade bans immediately take place after FMD incidents are reported, and the affected industry suffers from productivity losses due to depopulation and the specific effects of the disease. The specific characteristics of each country, such as dependence on exports, livestock-population demographics, disease-control policies, consumer reaction, value of livestock, etc, make it difficult to extrapolate the experiences in one country to another. Thus, the consequences of an outbreak are closely related to the specific characteristics of the country analyzed.

The specific characteristics of the Mexican cattle industry, like the differentiated production practices by region and low exports, make it particularly interesting, since most studies on the effects of FMD relate to countries with high exports. We specifically simulate the consequences of a hypothetical FMD outbreak under different mitigation scenarios. Our results will provide guidance when selecting different invasive species management policies. This study analyzes a relevant policy issue for the Mexican cattle industry. It is important for policy makers in Mexico to understand the potential impacts of an FMD outbreak and the consequences of the different mitigation policies to select the optimal one.

This article complements the literature by analyzing the effects of a hypothetical FMD outbreak in the Mexican cattle industry. We develop a conceptual bioeconomic model that incorporates dynamic effects. This model allows us to simulate the effects of different mitigation strategies, including producer and consumer responses. To the best of our knowledge, this is the first study to formally analyze the effects of a hypothetical FMD outbreak in the Mexican cattle industry.

Our results provide evidence suggesting the potential gains due to increased traceability and depopulation of latent infectious herds. However, it is important to consider the cost of implementing the necessary measures. The optimal depopulation rate will be the one where marginal cost equals marginal benefit. At this point, we can say that the two more reasonable scenarios correspond to a 60 to 70 percent depopulation rate of the latent infectious herds.

CHAPTER TWO

THE EFFECTS OF CHANGING SANITARY AND PHYTOSANITARY BARRIERS TO TRADE ON REVENUE AND SURPLUS

Introduction

The Sanitary and Phytosanitary Measures Agreement of the World Trade Organization (WTO) allows its members to set standards on food products to protect domestic consumers. In practice, sanitary and phytosanitary (SPS) barriers take the form of import standards or regulations that reflect the country's concern for SPS issues that could harm domestic production. These concerns include the introduction of disease or other pests. However, some claim that SPS barriers exist in certain countries to protect domestic producers from international competition (Yue, Beghin and Jensen 2006).

Apples represent the third most valuable fruit crop in the United States, after grapes and oranges (Dimitri, Tegene and Kaufman 2003). The United States represents the second largest producer and one of the top five exporters of apples in the world. However, according to USDA/FAS (2006) "trade issues continue to be a significant barrier for US apples in certain destination markets". Specifically, SPS barriers related to fire blight, codling moth, apple maggot and other pests limit or prohibit US apple exports to some countries, as well as impose additional costs on US apple producers and exporters (Krissoff, Calvin and Gray 1997). SPS barriers may also reduce the flow of apples into a country by imposing quarantine restrictions that delay shipments. Many argue SPS requirements restrict exports beyond what scientists consider necessary to protect the domestic product, and reducing SPS barriers will decrease costs to producers and increase trade.[1] We examine the effect of SPS barriers to trade imposed by China, India, Mexico and Taiwan on the Washington State apple industry. Washington State production accounts for nearly 60 percent of the US produced apples, and nearly 85 percent of the US exported apples. Specifically, we address the effects of changing the level of SPS barriers to trade on the revenue received by Washington State producers, and the economic surplus of importers and exporters.

Some work has been done regarding the demand for US apples in other countries and the effects of removing or reducing trade barriers. Different approaches have been taken. Import demand, export demand, gravity equation and general or partial equilibrium models are commonly used for trade estimation (Arize 2001; Calvin and Krissoff 1998 and 2005; Devadoss and Wahl 2004; Krissoff, Calvin and Gray 1997; Seale, Sparks and Buxton 1992; Yue, Beghin and Jensen 2006). The price wedge approach represents the most common method used to calculate an SPS tariff equivalent (Calvin and Krissoff 1998 and 2005; Krissoff, Calvin and Gray 1997; Yue, Beghin and Jensen 2006), which measures the difference in price between the imported good and the product in the domestic market. Researchers attribute this difference to transportation costs, tariffs and non-tariff barriers. The limitations of this method include: the impossibility to distinguish between the different barriers; the data available are rarely specific enough to reflect differences in quality of imported products; and domestic goods are assumed to be perfect substitutes for imported goods, which most likely does not accurately describe the market (Beghin and Bureau 2001).

Import and export demand models usually only yield the corresponding import and export demand elasticities, without analyzing trade barriers. Then, others incorporate those elasticities to evaluate the effects of trade barriers instead of estimating the elasticities directly.

[1] It should be noted that the scientific levels themselves generate significant debate.

Using previously generated elasticities, some examine the effects of removing trade barriers on the demand for US apples (Krissoff, Calvin and Gray 1997; Calvin and Krissoff 1998 and 2005). However, this method does not allow testing for the significance of the trade barriers. Two studies analyzing trade barriers, Yue, Beghin and Jensen (2006), and Devadoss and Wahl (2004), estimate their own elasticities and analyze the effect of reducing barriers to trade.

Krissoff, Calvin and Gray (1997) examine the effects of removing SPS requirements in Japan, South Korea and Mexico on US apple exports to those countries. Calvin and Krissoff (1998 and 2005) quantify the SPS barriers for US apples in Japan and estimate the trade and welfare effects for Japan of removing those barriers, specifically for Fuji apples. These authors use a partial equilibrium model to estimate trade flows simulating a reduction in SPS barriers to trade. Yue, Beghin and Jensen (2006) estimate the tariff equivalent of technical barriers to trade for apples in Japan. Afterward, they evaluate the effect of removing the Japanese barriers on US apple exports using the gravity equation. All these studies use the price wedge approach to estimate the tariff equivalent of the SPS barriers to trade. These studies yield different results, while Krissoff, Calvin and Gray (1997) and Calvin and Krissoff (1998 and 2005) find great increase in US apple exports with the removal of SPS barriers, Yue, Beghin and Jensen (2005) find limited export increase for US apples after removing the barriers in Japan.

Devadoss and Wahl (2004) estimate supply, demand and excess supply equations to examine welfare effects under different trade scenarios reducing the ad valorem tariff for apples in India. They conclude that India will greatly benefit from reducing trade barriers. The different methods used in the articles mentioned provide different estimates that translate into different results, some times yielding contradictory conclusions.

Some evidence suggests that SPS restrictions greatly reduce the amount of US apple exports. Estimates of the increased value of US apples exported if SPS barriers are reduced or eliminated vary by author and country, ranging from $5 million US dollars (USD) to $280 million USD, with most estimates in the $5 to $50 million USD range (Krissoff, Calvin and Gray 1997; Northwest Horticultural Council 2004; Loveland and Hamilton 2007). We incorporate and improve some of the methodology used in the previous studies to obtain more precise estimates.

We estimate the complete system of equations that characterize all stages of the export model, and we incorporate an estimate of the cost of complying with the SPS regulations. This study complements the literature by including a direct estimate of the SPS compliance costs, by analyzing countries not thoroughly studied previously and by estimating price elasticities while including SPS costs in the model. Then, we estimate export quantity changes for Washington State apples given specific changes on SPS costs. This allows us to calculate the associated revenue changes for Washington producers with different SPS costs. Furthermore, we estimate welfare changes by calculating changes in importers' and exporters' surplus. Our results yield estimates to provide policy recommendations that can be used by the industry to argue for the reduction of SPS barriers in other countries.

The rest of the article proceeds as follows. We present the model, including the theoretical background to derive the import demand and export supply equations, information on SPS restrictions for each country studied, and empirical specification in the next section. We follow with the description of the data and empirical issues. We then present results. Conclusions and a discussion of implications occur in the final section.

Import Demand and Export Supply

Theoretical Background

Our analysis starts by examining the Washington State apple industry to specify the demand and supply equations used for the revenue and surplus simulations. We recognize three agents involved in the apple export model: Washington State producers, exporters, and importers in China, India, Mexico and Taiwan. We choose these countries since they belong to the 2005/2006 ten largest export markets for Washington apples. And because they also offer an interesting mix of SPS restrictions and market characteristics as described in the next subsection. Producers provide the apples and are not involved in the export decision, thus we do not include them directly in the export model. Exporters and importers are the only agents directly implicated in the export model and export decision. SPS regulations affect producers, specifically through revenues received. To include the SPS barriers effect on producers, we calculate their revenue changes given different SPS scenarios. Additionally, we calculate surplus changes for importers and exporters under different SPS scenarios.

Washington State apple producers require the services of warehouses or exporters for the commercialization of their product. Some producers own the warehouses, while others contract for the provided services. Typically warehouses do not buy the apples, they provide the intermediary service to the producers, and charge them for it. Warehouses are solely responsible for the export decision; producers have no input in this decision.

Warehouses take charge of sorting, grading, packing and storing the apples and also the sales, marketing, and paperwork related to exports and regulation compliance. Warehouses may contract with other companies or provide all or some of these services internally. This decision usually depends on the country to which apples are exported. All the SPS paperwork occurs at the warehouse level. Only a few countries require SPS regulations that impose a direct cost on the producer by requiring extra steps in the production method, for example orchard inspections. SPS regulations directly affect warehouses not only because they have to comply with the paperwork and inspections, but also because SPS regulations limit the quantity exported by requiring quarantine measures or other fumigation treatments that delay shipments and make the apples more expensive. Further, the exporter incorporates the cost of complying with the SPS regulations specific for the country into the decision making process.

The importer takes responsibility for paying the transportation costs from the warehouse to the importing country, and the corresponding ad valorem tariffs and taxes if applicable. The importer directly pays the warehouse Free On Board (FOB) prices in USD for the apples.[2] These FOB prices are determined internationally and depend on the variety, size, grade and packaging of the apples. Exchange rate fluctuations may play an important role since the importer pays the product in USD.

The export model consists of the demand function for importers (import demand equation) and the supply function for warehouses or exporters (export supply equation) given that only importers and exporters make the export decision. To derive the import demand and export supply equations, we start by specifying an industry indirect profit function for importers in each country studied and exporters in Washington. We assume that importers and exporters represent price taking firms. China, India, Mexico and Taiwan represent small players in apple imports.[3] In the case of the United States, each of the several individual exporting firms also represents small players in apple exports.

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[2] FOB price quotations include the cost of loading the product onto the transportation carrier, while the transportation cost and insurance are not included.
[3] China has dramatically increased apple imports in the last 10 years, but it remains a small player in the international arena regarding apple imports.

We represent the importers' profit as a function of output price, input prices, ad valorem tariff, and exchange rate (Diewert and Morrison 1988). The indirect profit function for the importing industry can be defined in a general form by:

(1) $$\Pi_m(p,w,TR,ER) = \Pi_m(y(p,w,TR,ER),x(p,w,TR,ER)),$$

where $\Pi_m(p,w,TR,ER)$ refers to the indirect profit function for the importing industry; *p, w, TR, ER, y,* and *x* represent vectors of output prices, input prices, ad valorem tariffs, exchange rate, output quantities, and input quantities, respectively.

Applying Hotelling's Lemma to the indirect profit function for the importing industry, we derive the conditional factor input demand (import demand) equation for apples:

(2) $$\frac{\partial \Pi_m(p,w,TR,ER)}{\partial w} = -x(p,w,TR,ER).$$

We represent the exporters' profit as a function of output prices, input price, and SPS costs. The indirect profit function for the exporting industry can be defined in a general form by:

(3) $$\Pi_x(p,w,SPS) = \Pi_x(y(p,w,SPS),x(p,w,SPS)),$$

where $\Pi_x(p,w,SPS)$ refers to the indirect profit function for the exporting industry; *p, w, SPS, y,* and *x* represent vectors of output prices, input prices, SPS costs, output quantities, and input quantities, respectively.

We obtain the conditional factor output supply (export supply) equation for apples by applying Hotelling's Lemma to the profit function for the exporting industry:

(4) $$\frac{\partial \Pi_x(p,w,SPS)}{\partial p} = y(p,w,SPS).$$

We estimate the import demand (equation 2) and export supply (equation 4) equations as explained in the empirical specification section.

SPS Requirements for Washington Apples in China, India, Mexico and Taiwan

Each importing country has different SPS requirements for apples, which are specific to each exporting country and need to be characterized in the export supply equation. Even though some countries impose SPS restrictions, these restrictions may or may not distort trade. In this subsection we describe and analyze the SPS restrictions imposed by China, India, Mexico and Taiwan on Washington apples.

Due to SPS concerns, China only allows the varieties Red Delicious and Golden Delicious to be exported from the US (Northwest Horticultural Council 2006). Even so, exporters in the US and other countries export different varieties like Granny Smith and Gala to Hong Kong and then the local importers distribute these apples in China (what Shields and Huang (2004) call the “grey market”). This situation makes it impossible to obtain an accurate analysis of US apple exports to China (Shields and Huang 2004). Nevertheless, it provides evidence suggesting that demand for apples in China may outweigh the concerns reduced by imposing SPS barriers. SPS regulations add one more step in the supply chain, without necessarily limiting the actual number of apples imported in China.

According to USDA/FAS (2007) “as the Chinese become more aware of apple varieties and quality, their demand for premium apples will grow”. Fresh produce imports have already increased dramatically in the last ten years, almost ten-fold from the mid-nineties to 2006. Huang and Gale (2006), and Shields and Huang (2004) also expect this trend to increase. Evidence suggests that demand for high quality and diverse varieties of apples is an important driving force of apple trade in China, regardless of SPS regulations.[4]

[4] Washington apples are not considered close substitutes for Chinese, Indian or Mexican domestic apples (Deodhar, Landes and Krissoff 2006; Scarlett 2006; Powers 2006).

The situation in India differs since many believe that SPS barriers have not been enforced (Deodhar, Landes and Krissoff 2006). However, if the Indian government enforces the SPS barriers, these SPS barriers may pose a potential threat to Washington apple imports. It should be noted that since 2001, India has imposed a 50 percent ad valorem tariff for apples, which represents the maximum rate the World Trade Organization authorizes. The tariff increased from 40 to 50 percent in 2001 when India removed quantitative restrictions on apples. This suggests SPS barriers could be enforced if the WTO requires India to lower its ad valorem tariff.

Washington State exporters and producers view Mexico and Taiwan as two countries with burdensome SPS requirements. Mexico imposes anti-dumping duties to US red and golden delicious apples since September 1st, 1997 (USDA/FAS 2007).[5] These represent the two main varieties exported to the Mexican market. The anti-dumping duties started at a rate of 101.1 percent and have been eliminated, re-imposed, and decreased since then. The current anti-dumping duty is 47.05 percent for most apple exporters. The Northwest Fruit Exporters (NFE), an organization that represents producers when exporting their products to different countries, exports most apples from the Pacific Northwest to Mexico. Approximately 90 percent of US apples exported to Mexico come from the Pacific Northwest. The Northwest Horticultural Council and NFE have been trying to reach an agreement with the Mexican government to lower or suspend the anti-dumping duties. Currently, NFE is negotiating an agreement that includes the establishment of a floor price for apples exported by NFE (USDA/FAS 2007).

Mexico requires producers to comply with a detailed work plan. NFE takes responsibility of supervising and facilitating the compliance process. The work plan relates to phytosanitary policies and has been effective in keeping US apples out of the Mexican market

[5] Anti-dumping duties are the duties imposed by an importing country when an exporting country prices its product at a price below the own domestic price or below its production cost.

until most of the domestic crop has been marketed (Zertuche 1995). The work plan includes the inspection of growing and shipping areas, a cold storage treatment, and extensive inspections of the fruit prior to shipping.

Taiwan also requires US producers to follow an extensive work plan to export their product. After two codling moth incidents in 2002 which disrupted US apple exports to Taiwan, in August 2003, the US and Taiwan agreed on a new systems approach quarantine work plan for apples (Miller 2003). This work plan includes orchard certifications, packing house registration, a cold storage treatment and extensive inspections. It also includes a three-strike system for codling moth detection, in which the whole Taiwanese market closes to US apples if three detections of codling moth in independent shipments per apple season occur. From December 2004 to April 2005 the Taiwanese market remained closed to US apples due to three codling moth incidents. Two codling moth detections occurred in the past season, they imposed a significant burden on US exporters and producers.

Empirical Specification

We use the normalized quadratic functional form to describe both importers' and exporters' profit functions. Due to its flexibility and properties such as the estimation of own- and cross-price and substitution elasticities, and homogeneity in prices (through price normalization), we consider the normalized quadratic to be an adequate functional form (Diewert and Morrison 1986; Featherstone and Moss 1994; Marsh 2005; Shumway, Saez and Gottret 1988). We represent the profit function for the importing industry as:

$$\begin{aligned}\Pi_m^*(mp^*) = \alpha_0 + \sum_{i=1}^{k} \alpha_i mp_i^* + \frac{1}{2}\left(\sum_{i=1}^{k}\sum_{j=1}^{k} \alpha_{ij} mp_i^* mp_j^*\right) + \alpha_t TR + \sum_{i=1}^{k} \alpha_{it} mp_i^* TR \\ + \frac{1}{2}\alpha_{tt}(TR)^2 + \alpha_e ER + \sum_{i=1}^{k} \alpha_{ie} mp_i^* ER + \frac{1}{2}\alpha_{ee}(ER)^2\end{aligned} \tag{5}$$

where $\Pi_m^* = \Pi_m / wp$ and $mp_i^* = mp / wp$ refer to the normalized profit and import or input prices for importers, and *wp* corresponds to the wholesale or output price. Subscript *i* represents the different countries exporting apples to the importing country and subscript *k* represents the number of exporting countries to that country. *TR* refers to the ad valorem tariff rate and *ER* refers to the exchange rate, both specific for the importing country. The corresponding import demand equations after applying Hotelling's Lemma are:

$$(6) \qquad -mq_i = \alpha_i + \sum_{j=1}^{k} \alpha_{ij} mp_j^* + \alpha_{it} TR + \alpha_{ie} ER$$

for *i*=1,…,*k*., where *mq* corresponds to the imported quantity from the United States by country *i*. The import demand equation for Mexico also includes an anti-dumping duty variable.

We represent the profit function for the exporting industry as:

$$(7) \qquad \begin{aligned} \Pi_x^*(xp^*) = \beta_0 + \sum_{i=1}^{n} \beta_i xp_i^* + \frac{1}{2}\left(\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} xp_i^* xp_j^*\right) + \beta_s SPS + \sum_{i=1}^{n} \beta_{is} xp_i^* SPS \\ + \frac{1}{2}\beta_{ss}(SPS)^2 + \beta_t T + \sum_{i=1}^{n} \beta_{it} xp_i^* T + \frac{1}{2}\beta_{tt}(T)^2 \end{aligned}$$

where $\Pi_x^* = \Pi_x / pp$ and $xp_i^* = xp / pp$ refer to the normalized profit and export or output prices for exporters, and *pp* represents the producer or input price. Subscript *i* refers to the different countries importing apples from Washington State and subscript *n* refers to the number of countries that Washington State exports to. *SPS* corresponds to the cost of complying with the SPS regulations specific to each country. *T* represents a time trend included to capture residual effects like technology and consumption changes. In the equation for China, we included a time trend squared given the quadratic trend in exported quantity.

The corresponding export supply equations after applying Hotelling's Lemma are:

$$(8) \qquad xq_i = \beta_i + \sum_{j=i}^{n} \beta_{ij} xp_j^* + \beta_{is} SPS + \beta_{it} T$$

for i=1,…,n., where xq represents the exported quantity from the United States to country i. The export supply equation for Taiwan also includes a binary variable equal to one for time that the three-strike policy has been in place from August 2003 to date, and zero otherwise.

Once we obtain the estimated coefficients on the import demand and export supply equations, we calculate the corresponding elasticities. Then, we use those elasticities to simulate revenue and quantity changes for Washington State apple producers when increasing and decreasing SPS costs. Finally, we simulate welfare effects by calculating the associated changes in importers' and exporters' economic surplus.

Data and Empirical Issues

We use monthly data from January 1995 to March 2007 for China, Mexico and the United States, from January 1999 to March 2007 for India, and from January 1996 to March 2007 for Taiwan. The import quantities and values for all countries involved in the analysis consist of kilograms (kg) and USD for imports of fresh apples (Harmonized System code 080810) for China, India, Mexico, and Taiwan. We transformed quantities to 1,000 pounds and prices to USD/pound. The import valuation occurs in Cost, Insurance and Freight (CIF) Import Value, except for Mexico that reports import valuation in FOB prices.[6] We calculate unit import prices (CIF prices in USD/kg or FOB prices in USD/kg for Mexico) for the United States and its main competitors in each market by dividing import value by quantity imported for each country (Global Trade Atlas). We include the main suppliers of apples to each country studied as competitors for the United States (Global Trade Atlas). The competitors included in the import demand equation for China are New Zealand and Chile; China and New Zealand are included in

[6] CIF value includes insurance costs, transportation and miscellaneous charges to the first port of arrival in the importing country.

the equation for India; Canada, Argentina and Chile are included for Mexico; and Japan, Chile and New Zealand are included for Taiwan. Not all countries import apples from the United States or its main competitors in all months and thus, prices and quantities are not available for the complete time series.

Fred Gale, Senior Economist at the Economic Research Service, USDA, provided monthly retail prices of Fuji apples for China from January 1995 to September 2007. We obtained monthly wholesale prices of apples for India from May 2000 to September 2007 from the Agricultural Marketing Net of the Indian Government (website: http://dacnet.nic.in/dmi/agmarkweb/SA_Pri_Month.aspx). Monthly wholesale prices of Red Delicious, Golden Delicious and Starking apples for Mexico from January 1995 to September 2007 come from the Sistema Nacional de Información e Integración de Mercados of the Secretaría de Economía (website: http://www.economia-sniim.gob.mx/). We used monthly wholesale prices of Red Delicious, Golden Delicious, and Fuji apples for Taiwan from January 1996 to September 2007 from Taiwan's Council of Agriculture (website: http://amis.afa.gov.tw).

We obtained information on tariffs from the Foreign Agricultural Service of the USDA, the TRAINS database of the United Nations Conference on Trade and Development, and the Northwest Horticultural Council website (www.nwhort.org). Monthly exchange rate data for China, India, Mexico and Taiwan come from the Pacific Exchange Rate Service, Sauder School of Business, University of British Columbia. In the import demand equation for Mexico, we added an anti-dumping variable, obtained through the Foreign Agricultural Service of the USDA.

The export quantities and values, similar to the import data, consist of kg and USD for exports of fresh apples for the United States. We transformed quantities to 1,000 pounds and prices to USD/pound. The export valuation occurs in Free Along Ship (FAS) Export Value.[7] We calculate unit export prices (FAS prices in USD/kg) for the United States to each market by dividing export value by quantity exported to each country (Global Trade Atlas). The competitors included in the supply equations correspond to the main destinations for US apples (Global Trade Atlas). The specific competitors included in the export supply equation for China and Taiwan are Canada and Mexico; Canada, Mexico and the US retail price are included in the equation for India; and Canada and the United Kingdom are included for Mexico Some discrepancies exist in the data depending on the reporting country. US apple exports (reported by the United States) do not necessarily precisely match with imports of US apples (reported by each country studied). Monthly retail prices in USD/pound for red delicious apples in the United States come from the Bureau of Labor Statistics (website: http://www.bls.gov/data/home.htm). We obtained producer prices by month in Washington State from the National Agricultural Statistics Service. We converted these prices from US cents/pound to USD/pound.

We used two methods to calculate the SPS costs. First, we conducted telephone interviews with apple exporters. We identified 21 apple exporters in Washington State as potential participants of the interviews. From this sample, we obtained 13 complete interviews. Second, we contacted the Washington State Department of Agriculture (WSDA), to obtain information regarding costs associated with the various certificates and inspections for each country. Jason Kelly, Communications Director, WSDA provided this information (including changes over time). With the information from the telephone interviews to exporters and the WSDA, we calculated the price in USD per 1,000 pounds to comply with the SPS regulations to each of the countries analyzed.

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[7] FAS value includes the value of exports at the export port including inland transportation, insurance and other costs of placing the goods alongside the carrier. This quotation excludes loading charges, freight, and insurance.

In the export supply equation for Taiwan we added a three-strike variable. We obtained information on this variable through the Foreign Agricultural Service of the USDA. We present summary statistics for all variables used in the estimation in the appendix.

Empirical Issues

In order to provide accurate estimates, we performed tests for endogeneity of prices, anti-dumping duty and three strikes; unit root; autocorrelation; homoskedasticity; normality; and independence of the import demand and export supply equations. We also calculated the correlation among residuals of the import demand and export supply equations. Table A5 contains these results. Import and export prices, the anti-dumping duty variable in the Mexico import demand equation and the three strikes variable in the Taiwan export supply equation are exogenous. We reject the hypothesis of unit root in all equations. Autocorrelation of order one occurs in most equations, except the import demand equations for Mexico and Taiwan. We reject the homoskedasticity assumption in all export supply equations and fail to reject homoskedasticity in all import demand equations. We reject the hypothesis of normality in all equations except the import demand equations for Mexico and Taiwan. We reject the hypothesis of independence of the import demand and export supply equations for all countries. Finally, all countries present correlation among residuals of the demand and supply equations, ranging from 0.48 to 0.81.

We correct for heteroskedasticity in the estimation method as described in the results section. We added a one-month lag of the dependent variable and a binary variable describing the apple season in the corresponding country to the corresponding equation to account for autocorrelation in the data.[8] An economic as well as an econometric justification exists to include a one-month lag in the model since a one-month lag of the dependent variable supports the theory of adaptive expectations (Evans and Honkapohja 2001), given that apple transactions occur on a short term basis.

We normalize prices in the demand equations using the corresponding wholesale prices in each country studied.[9] In the import demand equation for Mexico, we do not use the exchange rate variable.[10] In the case of the supply equations, we normalize prices using the Washington State producer price.[11] We do not include the US retail price in the export supply equations for China, Mexico and Taiwan.[12]

The ad valorem tariff variable does not have enough variation in the time period and countries studied, and the import demand equations do not have a large enough number of observations to confidently estimate and identify the shift effect for this variable. Thus, we cannot include ad valorem tariff in the import demand equations.

Results

We estimate the complete set of import demand and export supply equations (equations 6 and 8) as seemingly unrelated estimation for each country using STATA (version 9.2). We consider the import demand and export supply equations as a complete set since they represent a joint export decision (Diewert and Morrison 1986; Goldstein and Khan 1978). Furthermore, results of the independence test and the correlation among residuals of the demand and supply equations provide empirical evidence supporting this claim (table A5 in appendix). The estimation occurs

[8] Apple season equals one during the apple season months in the corresponding country and zero otherwise.
[9] Except in the case of China, where we normalize using the Chile import price due to multicollinearity problems.
[10] Due to multicollinearity with the US import price variable.
[11] Except in the case of India, where we normalize using the Mexico export price due to multicollinearity.
[12] Due to multicollinearity with the Mexico export price.

in two steps to correct for the heteroskedasticity found in the data. In the first step, we use ordinary least squares to obtain estimates for each equation. In the second step, we use seemingly unrelated estimation to allow for correlation between the import demand and export supply equations and to correct for heteroskedasticity. The result provides a single parameter vector and a simultaneous robust covariance matrix.

We report the results from the seemingly unrelated estimation in tables 1 to 4 for China, India, Mexico and Taiwan, respectively. Estimated own price coefficients on the import demand equations have the expected negative signs. However, only the estimated own price coefficient in the import demand equation for Taiwan results significant.[13] Results show the expected positive and significant sign for the estimated own price coefficients in the export supply equations.

The estimated coefficients on SPS costs are insignificant for China and India, and significantly negative for Mexico and Taiwan. These results correspond to our expectations given the analysis on SPS requirements for each country studied. Given the specific characteristics and demand trends in China, we expect an insignificant coefficient on the SPS costs variable. Such a large and increasing demand for good quality fresh apples overshadows any restrictive effect of the SPS regulations. We find support for the claim that the extremely large demand for quality apples suggests that Chinese consumers want imported apples regardless of the SPS restrictions in this country. Our results also suggest that the increased demand in China outweighs the extra cost of complying with the SPS regulations. As expected, the estimated coefficient on SPS costs is insignificant for India given the belief that SPS barriers have not been enforced in India (Deodhar, Landes and Krissoff 2006). However, if the Indian

[13] We assume significance at the 10 percent for all results discussed in this section, unless otherwise noted. The corresponding tables contain the specific significance levels.

government enforces the SPS barriers, some believe these SPS barriers could pose a potential threat to Washington apple imports, and thus, we analyze this scenario. The significantly negative results for Mexico and Taiwan reflect the extreme SPS requirements imposed by these two countries, as explained in the SPS requirements subsection.

We calculated short run and long run import demand and export supply elasticities at the mean values for own price, competitors' prices, exchange rate, and SPS costs for each country, anti-dumping duties for Mexico and three-strikes for Taiwan, reported in tables 5 to 8. In the short run we assume that changes in quantity lagged one month are independent of changes in other explanatory variables. However, the long run represents the equilibrium condition in which quantities in all periods are equal, and thus, we assume that changes in quantity lagged one month are not independent of changes in other explanatory variables. All calculated own price short run elasticities are inelastic, however, the own price long run export supply elasticities become elastic for India, Mexico and Taiwan. Own price import demand short run elasticities range from -0.143 for Mexico to -0.735 for Taiwan, and the long run elasticities range from -0.143 for Mexico to -0.744 for China.[14] Own price export supply short run elasticities range from 0.446 for China to 0.873 for Taiwan, and the long run elasticities range from 0.659 for China to 3.702 for India.[15]

We find quite elastic short run elasticities of demand for exchange rate, ranging from -2.2 for Taiwan to -5.94 for India, and more elastic long run elasticities, ranging from -2.2 for Taiwan to -23.097 for China.[16] When the exchange rate increases, the local currency becomes more expensive relative to the US dollar. Therefore, the importing country can now afford fewer

[14] However, only the own price import demand elasticity for Taiwan results significant.
[15] All own price export supply elasticities result significant, except the long run elasticity for China.
[16] In the short run the value for China is -11.642, but insignificant, in the long run elasticities for all countries are significant.

apples. Our results prove consistent with this argument. The anti-dumping duty elasticity for Mexico is inelastic, -0.144 for both the short run and the long run. This becomes a surprising result given the high rate of the duty; however, the negative sign is expected, since it acts like a tariff increasing the transaction cost.

The elasticities of supply for SPS costs are significant for Mexico and Taiwan while insignificant for China and India. We expected these results given the extremely large demand for apples in China regardless of SPS barriers, the belief that SPS barriers are not imposed in India, and the extreme SPS barriers in Mexico and Taiwan, as discussed previously. We identify inelastic short run elasticities for Mexico (-0.403), and elastic long run elasticities (-1.1). In the case of Taiwan, we find both short run and long run elasticities elastic (-1.056 and -1.476). Finally, the three-strike elasticity is quite inelastic, 0.063 and 0.088 for the short run and long run, respectively. We expected a negative elasticity given that this policy introduced certifications, cold storage treatment, and inspections that increase costs. However, the significantly positive estimated coefficient on this variable may not be so surprising given that we find negative estimated coefficients on SPS costs and time trend. There exists the possibility that this coefficient and the associated elasticity capture an increasing quality trend, which represents consistency with complying with rigorous SPS regulations. Further, we find a negative net effect of these three variables.

We use the elasticities obtained to calculate the effects of changing SPS regulations on the three agents involved in the apple export model, producers, exporters and importers. We calculate surplus changes for importers and exporters but not for producers, since we only model the import demand and export supply equations. In the case of producers, we calculate quantity and revenue changes given the data available.

First, we use the SPS costs elasticities to calculate quantity and revenue changes for Washington State apple producers under three different scenarios, reported in table 9. As explained above, the situation in China has quite particular characteristics given the specific patterns of Chinese consumption and demand as well as the political situation. Thus, we did not include China in the simulations. The belief that SPS regulations have not been enforced in India until now explains our interest in analyzing the effects of increasing SPS costs for India. In the case of Mexico and Taiwan, both countries require the compliance of extensive work plans that US exporters consider not fully justified scientifically, so we analyze the effects of decreasing SPS costs for Mexico and Taiwan. We consider the following scenarios for India: 20, 50 and 100 percent increase in SPS costs; while for Mexico and Taiwan we consider: 20, 50 and 100 (complete elimination) percent decrease in SPS costs.

In general our results suggest consensus with the estimates in the literature, specially the more conservative ones.[17] Simulation results for India suggest that increasing SPS costs between 20 to 100 percent may decrease revenue for Washington apple producers between approximately 9 to 44 percent in the short run, and 51 to 257 percent in the long run ($530 thousand to $2.6 million, and $3.1 to $15.7 million, respectively), on average per year.[18] These results provide some evidence that if India increases the SPS barriers for apples there could be some revenue loss for Washington apple producers, but it may be insignificant.

Revenue simulation results for Mexico and Taiwan suggest that Washington apple producers may greatly increase revenue if SPS costs are reduced. Specifically, producers may increase revenue approximately between 8 and 40 percent in the short run, and between 22 and 110 percent in the long run ($4 to $22 million, and $12 to $60 million, respectively), on average

[17] The following revenue and surplus discussions refer to USD.

[18] It should be noted that the coefficient on SPS costs for India results insignificant. Nevertheless, we performed the simulation as if it resulted significant to provide a baseline for future comparisons.

per year if SPS costs decrease between 20 and 100 percent (complete elimination) in Mexico. In the case of Taiwan, decreasing SPS costs between 20 and 100 percent (complete elimination) may increase revenue for producers approximately between 21 and 106 percent in the short run, and between 30 and 148 percent in the long run ($8 to $42 million, and $12 to $58 million, respectively), on average per year. As mentioned before, both Mexico and Taiwan require US producers to comply with an extensive and burdensome work plan. Producer organizations, like NFE, and government agencies have been lobbying for the reduction and simplification of these work plans. Our results suggest that exports to Mexico and Taiwan may increase significantly if these countries reduce SPS barriers, which supports the lobbying efforts of the relevant organizations and agencies.

We also simulate the average changes per year in economic surplus for importers and exporters using a partial equilibrium model. We use the short run and long run own price import demand elasticities, own price export supply elasticities and SPS export supply elasticities.[19] With these elasticities we build a simple partial equilibrium supply and demand model and we introduce a shift in the supply curve caused by changes in SPS regulations, holding all other variables constant. Then, we calculate the surplus changes for importers and exporters associated with the different SPS scenarios. We use GAMS (version 22.2) for this simulation. We consider the same scenarios as in the revenue simulation (see table 10).

Surplus simulation results suggest that when exporting to India, both Washington exporters and Indian importers will lose if SPS costs increase, however this loss may be insignificant. In the short run, importers' surplus may decrease $1.8 to $8 million on average per year with a 20 to 100 percent increase in SPS costs. Exporters' surplus may decrease $0.6 to $2.8 million and total surplus may decrease $2.4 to $10.8 million on average per year. In the

[19] It should be noted that some of these elasticities are insignificant (see tables 6 to 8).

long run changes become more dramatic, as expected. If SPS costs increase between 20 to 100 percent, exporters' surplus may decrease $1.1 to $35.6 million on average per year.

Results for Mexico and Taiwan suggest that importers and exporters will significantly gain if SPS costs are reduced. In the case of Mexico, in the short run importers' surplus may increase approximately between $24 to $128 million if SPS barriers decrease between 20 to 100 percent (complete elimination), exporters' surplus may increase by $5 to $28 million, and total surplus may increase by $29 to $155 million on average per year. In the long run, if SPS costs decrease between 20 to 100 percent (complete elimination) importers' surplus may increase approximately $79 to $474 million, exporters' surplus may increase $6 to $38 million, and total surplus may increase $86 to $512 million on average per year.

In the case of Taiwan, short run results suggest that importers' surplus may increase approximately between $24 and $181 million if SPS costs decrease between 20 to 100 percent (complete elimination), exporters' surplus may increase by $20 to $147 million, and total surplus may increase by $44 to $327 million on average per year. In the long run, if SPS costs decrease between 20 to 100 percent (complete elimination), importers' surplus may increase approximately between $42 and $363 million, exporters' surplus may increase by $24 to $211 million, and total surplus may increase by $66 to $574 million on average per year.

Our results suggest that importers in Mexico and Taiwan, and exporters in Washington to Mexico and Taiwan may obtain great increases in surplus if SPS costs decrease even 20 percent. Naturally, the greater the reduction in SPS costs, the greater the resulting increase in surplus. These results complement the revenue simulation results suggesting that Washington State exporters could increase surplus with reductions in SPS costs. Furthermore, importers in Mexico and Taiwan may also increase surplus with a decrease in SPS costs. Hence, these results provide further evidence supporting the lobbying labor of producers and exporters organizations as well as government agencies to reduce SPS barriers in Mexico and Taiwan.

Conclusions

We start by characterizing a full export model to estimate the effects of changing SPS barriers to trade on Washington State apples in China, India, Mexico and Taiwan. We estimate the complete set of import demand and export supply equations and we calculate the corresponding import demand and export supply elasticities. We use the SPS costs elasticities obtained from the export supply equations in the revenue and surplus simulation. Specifically, we estimate quantity and revenue changes for Washington State apple producers, and importers' and exporters' economic surplus changes when increasing SPS costs 20, 50 and 100 percent for India, and decreasing SPS costs 20 and 50 percent, and completely eliminating SPS costs for Mexico and Taiwan.

The revenue simulation results provide evidence of potentially large gains for producers if Mexico and Taiwan reduce SPS costs. Revenue for Washington State apple producers may increase as much as 40 to106 percent in the short run, and 110 to 148 percent in the long run ($22 to $42 million and $58 to $60 million, respectively), on average per year per country, if SPS costs are completely eliminated. These results confirm Mexico and Taiwan as attractive markets for Washington apples with the reduction or elimination of SPS barriers. In India, we find a limited change in apple imports. This result represents good news for Washington State apple producers, given that it is believed that SPS barriers have not been enforced in India until now and SPS barriers could be enforced if India is required by the WTO to lower its ad valorem tariff. Thus, if India replaces the ad valorem tariff for apples with SPS restrictions, the revenue loss for

Washington apple producers may be not be large. Further, if India then reduces the SPS barriers we could see a large increase in US apple exports.

Results for the economic surplus simulation provide further evidence suggesting the great gains not only for producers but also for exporters and importers if SPS barriers decrease in Mexico and Taiwan and the limited effect for producers, exporters and importers with the enforcement of SPS barriers in India. Specifically, total surplus could increase in the short run between $29 and $327 million and in the long run between $86 and $574 million on average per year, depending on the specific reduction of SPS costs in Mexico and Taiwan.

Results for China seem to be driven by the dramatic increase in fresh produce imports in the last ten years. However, regardless of the SPS restrictions in this country, the extremely large demand for quality apples suggests that Chinese consumers pay for imported apples, making China an extremely attractive market for Washington apples.

The impact of changing SPS costs on the Washington State apple industry depends on the country analyzed. Countries like Mexico and Taiwan with more burdensome regulations put a great focus on protecting the domestic market and consequently, once these regulations are reduced the potential gains are quite large, as we expected. We also find that consumer demand plays a very important role and it should be considered jointly with government regulations. In the case of China, even though the government imposes SPS restrictions, such a large consumer demand overshadows the restrictions. From this analysis we could speculate that Mexico and Taiwan use SPS regulations to protect domestic producers, but China and India are not so concerned about actually enforcing SPS regulations, or using them to protect domestic producers.

Our results bring some promising information to the Washington State apple industry. We confirm China as an attractive market. Exports to Mexico and Taiwan may increase greatly if SPS barriers decrease. Even though exports to India may decrease if SPS barriers are enforced, the loss may not be large. In general, we provide further evidence of the potential gains for producers, exporters and importers if SPS barriers decrease.

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Tables

Table 1: Seemingly Unrelated Regression Estimation Results for China

Import Demand Equation Dependent Variable: Quantity lbs apples			**Export Supply Equation** Dependent Variable: Quantity lbs apples		
Variable	**Estimate**	**P-Value**	**Variable**	**Estimate**	**P-Value**
US Import Price	-394.27 (1727.25)	0.819	China Export Price	339.94* (196.93)	0.084
NZ Import Price	1868.37 (1608.08)	0.245	Canada Export Price	-68.31 (337.72)	0.840
China Retail Price	-348.56*** (101.31)	0.001	Mexico Export Price	149.30 (267.95)	0.577
Exchange Rate	-1488.39 (984.09)	0.130	SPS Costs	1362.49 (830.09)	0.101
			Time Trend Squared	0.0471*** (0.0155)	0.002
Quantity Lagged 1 Month	0.4960*** (0.1134)	0.000	Quantity Lagged 1 Month	0.3231*** (0.0606)	0.000
Apple Season	522.51*** (179.99)	0.004	Apple Season	451.08*** (159.19)	0.005
Constant	11527.63 (7764.89)	0.138	Constant	-2853.89** (1251.22)	0.023
Observations	77		Observations	105	
R-squared	0.5787		R-squared	0.6198	
Chi-squared	174.9		Chi-squared	673.99	

Note: robust standard errors reported in parenthesis, demand and supply prices are normalized, and ***, **, * denote 1, 5 and 10 percent significance level, respectively.

Table 2: Seemingly Unrelated Regression Estimation Results for India

Import Demand Equation Dependent Variable: Quantity lbs apples			Export Supply Equation Dependent Variable: Quantity lbs apples		
Variable	**Estimate**	**P-Value**	**Variable**	**Estimate**	**P-Value**
US Import Price	-542.21 (2511.24)	0.829	India Export Price	1930.33*** (587.98)	0.001
China Import Price	1471.49 (1709.81)	0.389	Canada Export Price	1258.88 (1167.85)	0.281
NZ Import Price	2427.88 (1550.29)	0.117	US Retail Price	-2755.21*** (686.89)	0.000
Exchange Rate	-356.47** (173.40)	0.040	SPS Costs	-712.25 (1006.30)	0.479
			Time Trend	-3.35 (7.52)	0.656
Quantity Lagged 1 Month	0.6175*** (0.1134)	0.000	Quantity Lagged 1 Month	0.8310*** (0.0571)	0.000
Apple Season	-2519.08*** (664.35)	0.000	Apple Season	137.46 (273.54)	0.615
Constant	14633.46* (8622.10)	0.090	Constant	7839.05*** (2440.98)	0.001
Observations	29		Observations	79	
R-squared	0.7703		R-squared	0.7884	
Chi-squared	249.72		Chi-squared	1320.30	

Note: robust standard errors reported in parenthesis, demand and supply prices are normalized, and ***, **, * denote 1, 5 and 10 percent significance level, respectively.

Table 3: Seemingly Unrelated Regression Estimation Results for Mexico

Import Demand Equation			**Export Supply Equation**		
Dependent Variable: Quantity lbs apples			Dependent Variable: Quantity lbs apples		
Variable	**Estimate**	**P-Value**	**Variable**	**Estimate**	**P-Value**
US Import Price	-6911.37	0.787	Mexico Export Price	7961.24***	0.000
	(25600.58)			(1156.97)	
Canada Import Price	-62119.46**	0.010	Canada Export Price	-4836.67***	0.000
	(24097.68)			(1202.05)	
Argentina Import Price	32237.74	0.334	UK Export Price	1463.94	0.151
	(33399.87)			(1020.46)	
Chile Import Price	24218.87	0.582			
	(44028.51)				
Exchange Rate	---	---	SPS Costs	-4373.67**	0.041
	---			(2141.95)	
Anti-dumping Duty	-21393.35***	0.006	Time trend	17.71*	0.092
	(7823.32)			(10.52)	
Quantity Lagged 1 Month	---	---	Quantity Lagged 1 Month	0.6337***	0.000
	---			(0.0108)	
Apple Season	---	---	Apple Season	-6994.83***	0.000
	---			(418.51)	
Constant	46076.57***	0.000	Constant	12608.23***	0.002
	(11974.71)			(4153.98)	
Observations	21		Observations	134	
R-squared	0.7154		R-squared	0.7379	
Chi-squared	659.64		Chi-squared	370000	

Note: robust standard errors reported in parenthesis, demand and supply prices are normalized, and ***, **, * denote 1, 5 and 10 percent significance level, respectively.

Table 4: Seemingly Unrelated Regression Estimation Results for Taiwan

Import Demand Equation			**Export Supply Equation**		
Dependent Variable: Quantity lbs apples			Dependent Variable: Quantity lbs apples		
Variable	**Estimate**	**P-Value**	**Variable**	**Estimate**	**P-Value**
US Import Price	-13113.23***	0.000	Taiwan Export Price	8680.92***	0.000
	(3614.40)			(1927.02)	
Japan Import Price	-797.49***	0.006	Canada Export Price	-24889.49***	0.000
	(289.27)			(2142.02)	
Chile Import Price	23270.12***	0.008	Mexico Import Price	16308.26***	0.000
	(8797.45)			(2984.10)	
NZ Import Price	-10184.29*	0.083	SPS Costs	-6404.88***	0.000
	(5882.17)			(1714.65)	
Exchange Rate	-662.53	0.104	Time Trend	-112.79***	0.000
	(407.33)			(16.22)	
			Three Strikes	4142.61**	0.019
				(1772.68)	
Quantity Lagged 1 Month	---	---	Quantity Lagged 1 Month	0.2841***	0.000
	---			(0.0240)	
Apple Season	---	---	Apple Season	---	---
	---			---	
Constant	32524.35**	0.012	Constant	43767.63***	0.000
	(12974.48)			(4406.98)	
Observations	34		Observations	120	
R-squared	0.4585		R-squared	0.5155	
Chi-squared	164.86		Chi-squared	23555.05	

Note: robust standard errors reported in parenthesis, demand and supply prices are normalized, and ***, **, * denote 1, 5 and 10 percent significance level, respectively.

Table 5: Elasticity Results for China

Import Demand Elasticities			Export Supply Elasticities		
Variable	Short-Run	Long-Run	Variable	Short-Run	Long-Run
Own Price	-0.375	-0.744	Own Price	0.446*	0.659
	(1.646)	(3.286)		(0.257)	(0.402)
New Zealand Price	1.769	3.510	Canada Price	-0.118	-0.174
	(1.524)	(3.060)		(0.583)	(0.864)
China Retail Price	-0.425***	-0.844***	Mexico Price	0.190	0.281
	(0.119)	(0.256)		(0.339)	(0.504)
Exchange Rate	-11.642	-23.097*	SPS Costs	2.240	3.310
	(7.987)	(13.407)		(1.365)	(1.919)

Note: standard errors reported in parenthesis, and ***, **, * denote significance at the 1, 5 and 10 percent level, respectively.

Table 6: Elasticity Results for India

Import Demand Elasticities			Export Supply Elasticities		
Variable	Short-Run	Long-Run	Variable	Short-Run	Long-Run
Own Price	-0.226	-0.590	Own Price	0.625***	3.702*
	(1.058)	(2.725)		(0.198)	(1.936)
China Price	0.541	1.415	Canada Price	0.560	3.314
	(0.632)	(1.705)		(0.528)	(2.982)
New Zealand Price	1.045	2.733	US Retail Price	-3.064***	-18.132***
	(0.703)	(1.909)		(0.796)	(5.737)
Exchange Rate	-5.940**	-15.528**	SPS Costs	-0.435	-2.573
	(3.098)	(7.274)		(0.615)	(3.701)

Note: standard errors reported in parenthesis, and ***, **, * denote significance at the 1, 5 and 10 percent level, respectively.

Table 7: Elasticity Results for Mexico

Import Demand Elasticities			Export Supply Elasticities		
Variable	**Short-Run**	**Long-Run**	**Variable**	**Short-Run**	**Long-Run**
Own Price	-0.143	-0.143	Own Price	0.484***	1.322***
	(0.525)	(0.525)		(0.071)	(0.215)
Canada Price	-1.120**	-1.120**	Canada Price	-0.406***	-1.110***
	(0.479)	(0.479)		(0.101)	(0.289)
Argentina Price	0.558	0.558	UK Price	0.115	0.315
	(0.611)	(0.611)		(0.080)	(0.219)
Chile Price	0.431	0.431			
	(0.760)	(0.760)			
Anti-dumping Duty	-0.144***	-0.144***	SPS Costs	-0.403**	-1.100**
	(0.054)	(0.054)		(0.195)	(0.522)

Note: standard errors reported in parenthesis, and ***, **, * denote significance at the 1, 5 and 10 percent level, respectively.

Table 8: Elasticity Results for Taiwan

Import Demand Elasticities			Export Supply Elasticities		
Variable	**Short-Run**	**Long-Run**	**Variable**	**Short-Run**	**Long-Run**
Own Price	-0.735***	-0.735***	Own Price	0.873***	1.220***
	(0.185)	(0.185)		(0.196)	(0.288)
Japan Price	-0.150***	-0.150***	Canada Price	-3.248***	-4.538***
	(0.050)	(0.050)		(0.282)	(0.297)
Chile Price	1.327***	1.327***	Mexico Price	1.553***	2.169***
	(0.470)	(0.470)		(0.281)	(0.348)
New Zealand Price	-0.598*	-0.598*	SPS Costs	-1.056***	-1.476***
	(0.344)	(0.344)		(0.282)	(0.404)
Exchange Rate	-2.200*	-2.200*	Three Strikes	0.063***	0.088**
	(1.288)	(1.288)		(0.026)	(0.036)

Note: standard errors reported in parenthesis, and ***, **, * denote significance at the 1, 5 and 10 percent level, respectively.

Table 9: Simulation Results for Increasing and Decreasing SPS Costs

	Average Quantity per year [a] (1995-2006)		Average Revenue per year [b] (1995-2006)		Percentage change in Revenue	
	Short-Run	**Long-Run**	**Short-Run**	**Long-Run**	**Short-Run**	**Long-Run**
India						
Actual	27.67	27.67	$6.10	$6.10		
20% increase	25.26	13.43	$5.57	$2.96	-8.70%	-51.46%
50% increase	21.65	-7.93	$4.77	-$1.75	-21.75%	-128.65%
100% increase	15.63	-43.53	$3.45	-$9.59	-43.50%	-257.30%
Mexico						
Actual	277.50	277.50	$54.70	$54.70		
20% decrease	299.86	338.55	$59.11	$66.74	8.06%	22.00%
50% decrease	333.42	430.13	$65.73	$84.79	20.15%	55.00%
Complete Elimination	389.34	582.76	$76.75	$114.88	40.30%	110.00%
Taiwan						
Actual	176.64	176.64	$39.57	$39.57		
20% decrease	213.94	228.78	$47.93	$51.26	21.12%	29.52%
50% decrease	269.90	306.99	$60.47	$68.78	52.80%	73.80%
Complete Elimination	363.17	437.35	$81.36	$97.99	105.60%	147.60%

[a] Units are million pounds
[b] Units are million USD

Table 10: Changes in Importers' and Exporters' Surplus

	Average Change in Importers' Surplus per year [a] (1995-2006)		Average Change in Exporters' Surplus per year [a] (1995-2006)		Average Change in Total Surplus per year [a] (1995-2006)	
	Short-Run	**Long-Run**	**Short-Run**	**Long-Run**	**Short-Run**	**Long-Run**
India						
20% increase	-$1.79	-$6.92	-$0.62	-$1.06	-$2.41	-$7.98
50% increase	-$4.30	$0 [b]	-$1.50	-$17.80	-$5.80	-$17.80
100% increase	-$8.02	$0 [b]	-$2.80	-$35.60	-$10.82	-$35.60
Mexico						
20% decrease	$23.99	$79.24	$5.18	$6.27	$29.18	$85.51
50% decrease	$61.41	$212.68	$13.27	$16.83	$74.68	$229.51
Complete Elimination	$127.59	$473.98	$27.57	$37.50	$155.16	$511.48
Taiwan						
20% decrease	$24.03	$41.52	$19.51	$24.12	$43.54	$65.64
50% decrease	$71.41	$133.00	$57.97	$77.26	$129.38	$210.26
Complete Elimination	$180.57	$363.33	$146.59	$211.07	$327.16	$574.39

[a] Units are million USD

[b] We constrained the associated equilibrium quantities for these scenarios to be nonnegative, and thus importers' surplus becomes zero.

Appendix

Table A1: Summary Statistics for China

Variable	Units	Obs.	Mean	Std. Dev.	Min	Max
Quantity	Pounds	147	1008.21	1329.82	0.00	5921.22
US Import Price	USD/pound	148	0.23	0.0934	0.08	0.46
Chile Import Price	USD/pound	91	0.27	0.0978	0.13	0.52
New Zealand Import Price	USD/pound	125	0.24	0.0960	0.10	0.41
China Retail Price	USD/pound	153	0.30	0.0683	0.20	0.68
Ad Valorem Tariff	Percentage	153	0.29	0.1455	0.10	0.40
Exchange Rate	CYN/USD	153	8.22	0.1726	7.52	8.46
China Export Price	USD/pound	116	0.30	0.0884	0.17	0.81
Canada Export Price	USD/pound	147	0.38	0.0525	0.29	0.50
Mexico Export Price	USD/pound	147	0.28	0.0531	0.19	0.52
WA Producer Price	USD/pound	148	0.22	0.0610	0.10	0.39
SPS Costs	USD/1000 pounds	153	1.79	0.1668	1.70	2.08

Table A2: Summary Statistics for India

Variable	Units	Obs.	Mean	Std. Dev.	Min	Max
Quantity	Pounds	99	2703.21	3309.06	0.00	17151.55
US Import Price	USD/pound	73	0.30	0.0497	0.19	0.50
China Import Price	USD/pound	63	0.27	0.0449	0.15	0.47
New Zealand Import Price	USD/pound	51	0.32	0.0516	0.20	0.57
India Wholesale Price	USD/pound	79	0.28	0.0779	0.10	0.49
Ad Valorem Tariff	Percentage	105	0.48	0.0422	0.40	0.50
Exchange Rate	INR/USD	105	45.27	2.10	40.13	48.96
India Export Price	USD/pound	88	0.29	0.0627	0.14	0.41
Canada Export Price	USD/pound	99	0.38	0.0570	0.29	0.50
Mexico Export Price	USD/pound	99	0.29	0.0568	0.24	0.52
US Retail Price	USD/pound	105	0.97	0.0920	0.81	1.26
SPS Costs	USD/1000 pounds	105	1.84	0.1852	1.70	2.08

Table A3: Summary Statistics for Mexico

Variable	Units	Obs.	Mean	Std. Dev.	Min	Max
Quantity	Pounds	147	23452.87	15573.84	443.87	84578.18
US Import Price	USD/pound	145	0.38	0.0875	0.18	0.62
Canada Import Price	USD/pound	92	0.33	0.0862	0.15	0.53
Argentina Import Price	USD/pound	34	0.35	0.0354	0.25	0.42
Chile Import Price	USD/pound	89	0.33	0.0534	0.24	0.51
Mexico Wholesale Price	USD/pound	153	0.56	0.0976	0.37	0.87
Ad Valorem Tariff	Percentage	153	0.10	0.0879	0.00	0.20
Anti-dumping Duty	Percentage	153	0.23	0.2944	0.00	1.01
Mexico Export Price	USD/pound	147	0.28	0.0531	0.19	0.52
Canada Export Price	USD/pound	147	0.38	0.0525	0.29	0.50
UK Export Price	USD/pound	147	0.35	0.0906	0.22	0.59
WA Producer Price	USD/pound	148	0.22	0.0610	0.10	0.39
SPS Costs	USD/1000 pounds	153	2.08	0.2137	1.94	2.45

Table A4: Summary Statistics for Taiwan

Variable	Units	Obs.	Mean	Std. Dev.	Min	Max
Quantity	Pounds	135	14578.88	12801.62	0.00	57750.12
US Import Price	USD/pound	128	0.30	0.1006	0.22	0.91
Japan Import Price	USD/pound	104	1.02	0.8687	0.46	3.87
Chile Import Price	USD/pound	88	0.30	0.0594	0.10	0.56
New Zealand Import Price	USD/pound	77	0.30	0.0883	0.10	0.82
Taiwan Wholesale Price	USD/pound	112	0.59	0.1873	0.19	1.47
Ad Valorem Tariff	Percentage	141	0.32	0.1270	0.20	0.50
Exchange Rate	TWD/USD	141	32.20	2.25	27.00	35.02
Taiwan Export Price	USD/pound	132	0.29	0.0647	0.14	0.48
Canada Export Price	USD/pound	135	0.38	0.0534	0.29	0.50
Mexico Export Price	USD/pound	135	0.28	0.0545	0.19	0.52
WA Producer Price	USD/pound	136	0.22	0.0622	0.10	0.39
SPS Costs	USD/1000 pounds	141	2.39	0.2657	2.18	2.82
Three Strikes	binary variable	141	0.35	0.48	0.00	1.00

Table A5: Results for the Assumptions Tests

	Country:	China	India	Mexico	Taiwan
Test	**Null Hypothesis**	**Test Statistic (P-Value)**			
Wu-Hausman	Import price is exogenous	-0.240	0.270	-1.470	-0.950
		(0.812)	(0.789)	(0.141)	(0.344)
Wu-Hausman	Export price is exogenous	-0.720	-1.180	1.610	0.290
		(0.478)	(0.237)	(0.108)	(0.775)
Wu-Hausman	Anti-dumping Duty / Three-Strikes is exogenous	---	---	-1.000	1.310
		---	---	(0.316)	(0.192)
Dickey-Fuller	Unit root	-6.046	-7.649	-4.854	-5.887
		(0.000)	(0.000)	(0.000)	(0.000)
Breusch-Godfrey LM	No autocorrelation in demand equation	11.400	10.402	0.574	1.575
		(0.001)	(0.001)	(0.449)	(0.209)
White's	Homoskedasticity in demand equation	13.910	9.180	21.000	11.17
		(0.456)	(0.819)	(0.397)	(0.942)
Shapiro-Wilk	Normality in demand equation	5.274	1.968	-0.455	0.416
		(0.000)	(0.025)	(0.675)	(0.339)
Breusch-Godfrey LM	No autocorrelation in supply equation	10.253	43.802	74.998	5.100
		(0.001)	(0.000)	(0.000)	(0.024)
White's	Homoskedasticity in supply equation	28.310	37.150	38.270	34.460
		(0.078)	(0.008)	(0.008)	(0.098)
Shapiro-Wilk	Normality in supply equation	5.201	3.962	5.156	2.993
		(0.000)	(0.000)	(0.000)	(0.001)
Breusch-Pagan	Independence of import and export equations	43.646	15.374	11.076	7.745
		(0.000)	(0.000)	(0.001)	(0.005)
Correlation among residuals of demand and supply equations:		0.813	0.728	0.726	0.477

CHAPTER THREE

WELFARE IMPLICATIONS OF WASHINGTON WHEAT BREEDING PROGRAMS

Introduction

Wheat is an important commodity for the United States and Washington State, both at the domestic and international levels. Land Grant Universities, such as Washington State University (WSU), invest in research to improve wheat characteristics that will benefit both producers and consumers. However, funds available for agricultural research are a scarce resource. Thus, the relevant policy question is if these public funds are being allocated efficiently. To justify future spending in wheat breeding programs, the providers of the majority of funds, state and federal legislators, need to be assured that each dollar being spent in wheat breeding programs is being put to the most efficient use. Measuring the welfare effects of the WSU wheat breeding programs represents an important contribution in understanding the value of these programs.

The main objective of this study is to calculate the welfare effects of the WSU wheat breeding programs and technology for producers and consumers in Washington State, Oregon, Idaho, the United States and the rest of the world. We also draw insights about the effects of cutting edge processes such as DNA fingerprinting in wheat breeding research. This study will make an important contribution to the literature since we use a detailed multi-region, multi-product and multi-variety model that includes spill-over effects, accounts for the limited substitution among the wheat classes and incorporates new technology, which has not been done before. Our results will be useful to decision makers in the government since we provide justification for funding the WSU wheat breeding program. Finally, this study will benefit producers and consumers, because it contributes to understanding the value of the wheat breeding programs and provides justification for them.

Through the years there have been several studies examining the effects on welfare of different wheat breeding programs. Studies related to the impact of wheat breeding research started as early as the 1970s (Blakeslee, Weeks, Bourque and Beyers 1973; Blakeslee and Sargent 1982; Brennan 1984; Edwards and Freebairn 1984; Zentner and Peterson 1984; Brennan 1989; Brennan, Godyn and Johnston 1989; Byerlee and Traxler 1995; Barkley 1997; Alston and Venner 2002; Heisey, Lantican and Dubin 2002; Brennan and Quade 2006). Models developed and became more sophisticated and accurate with time. Most approaches focus on economic surplus measures, based on partial equilibrium or econometric models. These studies also differ in the representation of varietal improvement, with yield increase being the most popular.[20] Some work has been done regarding the use of new technologies, specifically the potential benefits of genetically modified wheat research (Berwald, Carter and Gruère 2005; Crespi, Grunewald, Barkley, Fox and Marsh 2005).

Estimates of the benefits of wheat research programs due to yield improvements vary by author, time-frame, country and specific study. The average US farmer in 1980 could expect to receive additional $29 US dollars (USD) per acre for wheat production (Blakeslee and Sargent 1982). Barkley (1997) suggests that while the costs of the Kansas State wheat breeding program averaged $3.8 million per year for the period 1979 to 1994, average benefits per year to Kansas wheat producers were $52.7 million USD, $190 thousand USD to Kansas consumers, and $41.4 million USD to rest of the world consumers. Surplus for wheat producers in the rest of the world decreased an average of $40.7 million USD per year. In Canada, both producers and consumers benefit from wheat research, with annual social benefits of $49 to $143 million Canadian dollars

[20] A popular study to follow when calculating yield increase is Feyerherm, Paulsen and Sebaugh (1984).

depending on the specific scenario considered (Zentner and Peterson 1984). Heisey, Lantican and Dubin (2002) estimate that returns to international wheat breeding research are $1.6 to $6 billion USD in annual benefits given a total investment of $150 million USD per year.

Our work complements and contributes to the literature by looking at the different wheat classes independently, given that they are differentiated products, and by calculating welfare effects for the different regions using wheat varieties developed by WSU (Washington, Oregon and Idaho) in particular. Thus, we are able to calculate the spillover effects to Oregon and Idaho. Additionally, we simulate the effects of using DNA fingerprinting, a technology that can potentially reduce the development time by several years, and provide a price premium to producers. Our results provide evidence of the value of the WSU wheat breeding programs for consumers and producers, not only in Washington State but also in Oregon, Idaho, the United States and the rest of the world. Finally, we provide some observations about the value of the use of DNA fingerprinting.

The rest of the article proceeds as follows. The next section provides some background on wheat production and DNA fingerprinting. We follow with the development of the model. We next present the data used for the analysis. Scenarios and results are then presented for the WSU wheat breeding programs and DNA fingerprinting simulations. The article ends with some brief conclusions.

Background

Wheat ranks fifth in total production among all commodities in Washington State; and in the United States, Washington State is the fourth largest producer of wheat. Washington State is one of the largest wheat exporting states, with 85 to 90 percent of its crop being exported

(Washington Wheat Commission 2006). Due to favorable growing conditions soft white wheat is primarily grown in Washington. Wheat varieties in Washington are always being adapted to counteract specific issues that affect producers yield such as fungi and insects, as well as to meet producer demand for higher yielding varieties.

In addition to helping producers by increasing yield and / or quality, new varieties should also maintain or improve consumer desired characteristics, such as milling properties and the characteristics required for good quality bread, cakes, cookies or pasta, depending on the specific wheat class. Thus, wheat breeding programs are important to both producers and consumers. However, it is not always easy to justify increased expenditure in wheat breeding research because of the long period of time from the beginning of the trials to the adoption of these varieties by growers, and the fact that growers do not buy seed every year, but save some of the harvested grain to plant the following year or years (Heisey, Lantican and Dubin 2002).[21] Welfare implications of wheat breeding programs and technology are relevant concerns for associated interest groups and the public in general.

The Crop and Soil Sciences Department at WSU has several plant breeding programs, one of which is wheat. The wheat research program at WSU is funded by a mix of state and federal funds, with some contributions from the Washington Wheat Commission.[22] Varieties developed by the WSU wheat breeding programs account for the majority of the wheat acreage in the State (Jones 2006).

Table A1 in the appendix shows the number of acres planted to WSU varieties in Washington, Oregon and Idaho by wheat class from 2002 to 2006, as well as the acres to private varieties and the total number of acres. We can see a great amount of variation in the number of

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[21] It can take from 7 to 12 years to develop and market a new wheat variety.
[22] Funding levels vary by year and by source.

acres by origin and class over time. The main wheat class planted in Eastern Washington is soft white wheat. In 2002, 74 percent of soft white wheat acres was planted to varieties developed by WSU, compared to 61 percent in 2006.

Wheat is not a homogeneous product. The agronomic characteristics of the different varieties determine the end use of wheat, making the different wheat classes differentiated products. For example, flour made from hard wheat is mainly used for bread, soft wheat flour is mainly used for cakes and cookies and durum wheat flour is mainly used for pasta. The United States produces five major wheat classes: hard red winter (HRW), hard red spring (HRS), soft red winter (SRW), soft white winter (SWW) and durum wheat (DUR). Production of the different classes of wheat in the United States is highly segregated. HRW is grown mainly in Kansas and Oklahoma (Central Plains), HRS and durum wheat are grown mainly in North Dakota (Northern Plains), SRW is produced in the Corn Belt and Southern States, and SWW is grown in the Pacific Northwest, Michigan and New York (Koo and Taylor 2006). Given the limited substitutability for milling purposes among these wheat classes (Marsh 2005, Mulik and Koo 2006), it is important to analyze these different classes on their own when studying wheat for the United States. We specifically model each wheat class independently and we subdivide the classes corresponding to varieties developed at WSU into 7 regions. For Washington, Oregon, and Idaho, we subdivide each state in varieties developed by WSU and other, and the rest of the United States is comprised in the Other region.

Wheat breeding programs and producers could have large gains with the use of new technologies, like DNA fingerprinting, that can potentially reduce the development time (and cost) by several years, and could lead to a geographic origin premium for producers. DNA fingerprinting can be used in wheat breeding research to identify and catalog different wheat varieties. DNA fingerprinting can be a quick way to select parents with the widest range of genetic variability; it may reduce the development time of wheat varieties by several years (Cooke 2007). This technology can be used as a certificate of origin to identify Washington wheat (or by region, like in the case of wine) and obtain a quality premium. However, the segregation costs have to be considered as well to have a more accurate analysis.

Model

We divide the model section in three parts. First we present the general model following Alston, Norton and Pardey (1995), what we call the ANP model. Second, we expand the ANP model to incorporate the different wheat classes and regions. We extend this model to include two main regions, the United States and the rest of the world, and we further divide the United States by wheat class to get a multi-product model. Furthermore, we subdivide the wheat classes that the WSU wheat breeding programs have developed varieties for (HRW, HRS, SWW) into Washington State, Oregon, Idaho and other to obtain a multi-region model, where each state studied is further divided into production due to WSU varieties and other. In this way, we allow for spillover effects to Idaho and Oregon. We also incorporate cross commodity price effects to allow for limited substitution in demand among wheat classes. We call this model the WSU wheat breeding programs model. Third, we incorporate the effects of using new technology, like DNA fingerprinting, and we call this model the DNA fingerprinting model.

The ANP model is also similar to the ones presented in Brennan, Godyn and Johnston (1989), Byerlee and Traxler (1995), Edwards and Freebaim (1984), and Voon and Edwards (1992), and it has been used in most studies measuring economic surplus of agricultural research (Barkley 1997; Crespi et al. 2005; Heisey, Lantican and Dubin 2002; Nalley, Barkley and

Chumley 2006; etc.). Alston, Norton and Pardey (1995) provide a structured, detailed and well written overview of the methods used for economic surplus estimation, as well as the methods for agricultural research evaluation and priority setting. Consequently, we follow Alston, Norton and Pardey (1995) in the development of our theoretical equilibrium displacement model.

ANP Model

We start by defining the supply and demand equations that characterize the wheat market in general. By characterizing the supply and demand functions we can calculate the changes in consumer, producer and total surplus associated with a change in price due to a shift in the supply curve. We assume linear demand and supply functions. The model is divided in different regions: the region of interest (where the supply shift occurs), *W*, and other relevant regions to the study, *i=1, ..., R*. The corresponding supply equations are:

(1) $$Q_W = \alpha_W + \beta_W (P_W + k_W)$$

(2) $$Q_i = \alpha_i + \beta_i P_i, \quad i=1, \ldots, R,$$

where *Q* denotes the quantity of wheat supplied by the corresponding regions, *W* or *i*, *P* is the price for wheat, *k* represents a parallel shift down of the supply curve, α represents the intercept parameter and β the slope parameter. The demand equations are represented by:

(3) $$C_j = \gamma_j - \delta_j P_j, \quad j=W, 1, \ldots., R,$$

where *C* denotes the quantity of wheat demanded in the corresponding region *j*, γ represents the intercept parameter, and δ is the non-negative slope parameter. In equilibrium, total quantity supplied and total quantity demanded are equal, giving the following market clearing condition:

(4) $$\sum_j Q_j = \sum_j C_j, \quad j=W, 1, \ldots, R.$$

We substitute $k=KP_0$, such that K represents the vertical shift of the supply curve as a proportion of the initial price, P_0. Totally differentiating equations 1 to 3 allows us to re-write these equations in terms of relative changes and elasticities:

(5) $E(Q_W) = \varepsilon_W [E(P_W) + K_W]$

(6) $E(Q_i) = \varepsilon_i [E(P_i)]$, $i=1, \ldots, R$

(7) $E(C_j) = \eta_j [E(P_j)]$, $j=W, 1, \ldots, R$,

where E denotes relative changes, that is, $E(Z) = dZ/Z = dlnZ$; ε is the price elasticity of supply, and η is the price elasticity of demand. Now the market equilibrium condition is:

(8) $\sum_j ss_j E(Q_j) = \sum_j ds_j E(C_j)$, $j=W, 1, \ldots, R$,

where ss represents the corresponding supply share ($ss_j = Q_j / \sum_j Q_j$) and ds represents the corresponding demand share ($ds_j = C_j / \sum_j C_j$). This system of equations (5 to 8) can be solved to obtain the relative change in price:

(9) $E(P) = \dfrac{-K_W ss_W \varepsilon_W}{\sum_j (ds_j \eta_j + ss_j \varepsilon_j)}$, $j=W, 1, \ldots, R$.

Subsequently, equation 9 can be substituted into the region-specific supply and demand equations 5 to 7 to obtain specific effects on quantities. With this information we can calculate annual benefits from research-induced shifts in the wheat supply curve by estimating changes in consumer surplus (CS), producer surplus (PS), and total surplus (TS):

(10) $\Delta CS_j = -P_j C_j [E(P_j)][1 + 0.5E(C_j)]$

(11) $\Delta PS_j = P_j Q_j [E(P_j) + K_j][1 + 0.5E(Q_j)]$, $j=W, 1, \ldots, R$,

(12) $\Delta TS = \sum_j \Delta CS_j + \sum_j \Delta PS_j$

where PC and PQ represent the initial consumer and producer prices, respectively. In this way total surplus from the research-induced supply shift corresponds to the area below the demand curve and between the two supply curves. This area represents the sum of the cost saving due to the yield increase and the economic surplus due to the increment to production and consumption.

The main limitation of this model is that it assumes a parallel shift in the supply curve. Additionally, it requires linear demand and supply functions for the economic surplus formulas to be valid. However, the model is still general and flexible enough to accommodate a wide range of different market structures and characteristics.

WSU Wheat Breeding Programs Model

We can modify the ANP model to incorporate the different wheat classes and regions to build our own equilibrium displacement model. Our model represents partial equilibrium because it only looks at the wheat industry and assumes constant prices for all inputs used in wheat production. Since we are only interested in simulating the welfare effects due to yield improvements in WSU developed varieties, we hold all other yield improvements constant, including improvements due to technology, management practices and other wheat breeding programs.[23]

We extend the ANP model to include two main regions or submodels, the United States submodel and the rest of the world submodel, and we further divide the United States submodel by wheat class to get a multi-product model. Furthermore, we subdivide the wheat classes that the WSU wheat breeding programs have developed varieties for (HRW, HRS, SWW) into Washington State, Oregon, Idaho and other to obtain a multi-region model, where each state

[23] It should be noted that other states could be using wheat varieties with similar yield improvements, and thus, spillover effects may wash out once other yield improvements are considered.

studied is further divided into production due to WSU varieties and other (WA-WSU, WA-other, OR-WSU, OR-other, ID-WSU, ID-other). In this way, we allow for spillover effects to Idaho and Oregon. We also incorporate cross commodity price effects to allow for limited substitution in demand among wheat classes.

First we only analyze the US submodel, and we obtain the equilibrium prices and quantities for each wheat class, region and sub-region given a supply shift due to the yield improvement in WSU varieties. With those results, we get the aggregate effects for the United States submodel and we simulate the results of trading between the United States and the rest of the world. Thus, we can obtain results for the overall model. We then calculate the changes in consumer, producer and total surplus for each wheat class and region within the United States, as well as for the United States as an aggregate and the rest of the world associated with a change in price due to a shift in the supply curve for the regions using varieties developed at WSU. We assume that the shift is due to yield improvements obtained by using varieties developed by the WSU wheat breeding programs, holding everything else constant. That is, holding potential improvements due to other research programs and technology constant. The supply shift parameter, K, is calculated as the yield increase or improvement due to WSU varieties divided by the price elasticity of supply (Alston, Norton and Pardey 1995).

The specific supply and demand equations for the US submodel are:

(13) $E(Q_{i,a}) = \varepsilon_i [E(P_i) + K_{i,a}]$, *i = HRW, HRS, SRW, a = WA-WSU, OR-WSU, ID-WSU*

(14) $E(Q_{i,b}) = \varepsilon_i [E(P_i)]$, *b = WA-other, OR-other, ID-other, other*

(15) $E(Q_j) = \varepsilon_j [E(P_j)]$, *j = SWW, DUR*

(16) $E(C_n) = \sum_c \eta_{nc} [E(P_c)]$, *n, c = HRW, HRS, SRW, SWW, DUR*

Given that prices among wheat classes are not the same, we have a market equilibrium condition for each wheat class. Equation 17 corresponds to the equilibrium condition for HRW, HRS and SWW classes, and equation 18 to SRW and DUR:

(17) $\sum_{d} ss_{d} E(Q_{d}) = \sum_{d} ds_{d} E(C_{d})$,

d = WA-WSU, WA-other, OR-WSU, OR-other, ID-WSU, ID-other

(18) $E(Q_{j}) = E(C_{j})$

In overall model we aggregate the change in quantities produced, quantities consumed, and prices to obtain the corresponding changes in quantity produced, quantity consumed and price for the United States. Then we allow trade to occur between the United States and the rest of the world to obtain equilibrium prices and quantities for the rest of the world. This overall model assumes that changes in production within the United States will change the equilibrium prices and quantities in the rest of the world. We consider this a valid assumption given that the United States is a large player in the wheat world market. The United States is the largest wheat exporter in the world with almost half of the US wheat crop being exported (Vocke, Allen and Ali 2005). The demand and supply equations for the rest of the world (*ROW*), and the market equilibrium condition given trade between the United States and the rest of the world are:

(19) $E(Q_{ROW}) = \varepsilon_{ROW}[E(P_{ROW})]$

(20) $E(C_{ROW}) = \eta_{ROW}[E(P_{ROW})]$

(21) $\sum_{h} ss_{h} E(Q_{h}) = \sum_{h} ds_{h} E(C_{h})$, h = *US, ROW*

Finally, we calculate changes in consumer, producer and total surplus for each region and wheat class. Change in producer surplus for each region and wheat class is calculated as in the general equation for change in producer surplus (equation 11). However, the calculation of change in consumer surplus is somewhat different given the cross product prices in the demand equation for the different US wheat classes. In this case, the general equation for change in consumer surplus (equation 10) captures the change in consumer surplus plus the change in producer surplus for the regions without the shift in the supply curve (Alston, Norton and Pardey 1995). This is because we allow for cross-products effects, which provides feedback to demand through substitution in consumption. Thus, we calculate the change in consumer surplus for the United States by adding the change in consumer surplus for wheat classes with a shift in the supply curve (equation 22), and then subtracting the producer surplus for all regions without a shift in the supply curve (equation 23). Equation 10 is used to calculate changes in consumer surplus for HRW, HRS and SWW.

(22) $\Delta CS_{US}^{*} = \Delta CS_{HRW} + \Delta CS_{HRS} + \Delta CS_{SWW}$

(23) $\Delta CS_{US} = \Delta CS_{US}^{*} - \sum_{l} \Delta PS_{l}$,

where l = *HRW-WAother, HRW-ORother, HRW-IDother, HRW-Other, HRS-WAother, HRS-ORother, HRS-IDother, HRS-Other, SRW, SWW-WAother, SWW-ORother, SWW-IDother, SWW-Other, and DUR.*

DNA Fingerprinting Model

For the DNA fingerprinting simulation we are forced to make some assumptions, given that there is not enough information about DNA fingerprinting for wheat. This technology is not currently used in Washington State. We simulate the effects of all producers in Washington State using DNA fingerprinting and receiving a premium for their product. A proportion of consumers in Washington, the rest of the United States and the rest of the world are assumed to be willing to pay a premium for Washington wheat. We model this price premium as a quality demand shifter, represented by A. Producers are divided in three regions: Washington (*WA*), the rest of the United States (*RUS*) and the rest of the world (*ROW*). Consumers in each of those three regions are further divided in the ones consuming Washington wheat (*WA-WA, RUS-WA, ROW-WA*) and Other wheat (*WA-Other, RUS-Other, ROW-Other*).

The supply and demand equations, and the market equilibrium conditions are presented in the following equations. We have two market equilibrium conditions, to allow for different prices for Washington wheat and Other wheat.

(24) $E(Q_i) = \varepsilon_i [E(P_i)]$, $i = WA, RUS, ROW$

(25) $E(C_{ij}) = \eta_{ij} [E(P_{ij}) - A_{ij}]$, $j=WA, Other$

(26) $ss_{WA} E(Q_{WA}) = \sum_i ds_{i,WA} E(C_{i,WA})$

(27) $ss_{RUS} E(Q_{RUS}) + ss_{ROW} E(Q_{ROW}) = \sum_i ds_{i,Other} E(C_{i,Other})$

The consumers' and producers' surplus formulas are similar to the ones defined in equations 10 and 11, however, the shift parameter (A) is now included in the consumers' surplus equation, not in the producers' surplus equation.

(28) $\Delta CS_{ij} = -P_{ij} C_{ij} [E(P_{ij}) - A_{ij}][1 + 0.5E(C_{ij})]$

(29) $\Delta PS_i = P_i Q_i [E(P_i)][1 + 0.5E(Q_i)]$

Data

Annual data for production of wheat produced in Washington, Oregon and Idaho from 2002 to 2006 are available through the US Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) website (http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/). Detailed information on acreage by variety by state over time was obtained through the NASS

Statistical Bulletins by State. Annual data on price, production and consumption for the United States and the world are available through the USDA Economic Research Service Wheat Yearbook Tables (http://www.ers.usda.gov/data/wheat/). Annual prices were deflated to reflect 2006 dollars using the US consumer price index (CPI) obtained through the Bureau of Labor Statistics website (http://data.bls.gov/). The CPI was adjusted to represent 2006 dollars by changing the base year to 2006 instead of 1982-1984. Supply and demand elasticities are available from the literature.

We were not able to find consumption data for Washington, Oregon and Idaho. For these states, we calculated consumption proportionally to the state's population based on consumption for the whole United States. Population data for the United States, Washington, Oregon and Idaho were obtained through the Census Bureau website (http://www.census.gov).

The yield improvement data to calculate the supply shift parameter were obtained from the NASS website. Yield improvement was calculated as the marginal change in yield trend for spring and winter wheat. Unfortunately, there are no yield data by wheat class, only by wheat type (winter or spring). We calculated quantity produced for Washington, Oregon and Idaho for varieties developed by WSU and others using the acreage data by variety by state over time from NASS. The varieties were matched to a cultivar list and cross reference guide put together by Dr. Craig Morris from the Western Wheat Quality Laboratory, USDA. This reference guide contains information regarding the variety name, release date, source and origin, among others. Even though this list is not comprehensive, it gives a lower bound on the amount of acres planted to WSU varieties in Washington, Oregon and Idaho. We multiplied acres times yield by wheat type to get quantity produced for each wheat class and sub-region.

To simulate the effects of using DNA fingerprinting in Washington, we use data from 1987 to 2006 on wheat production, consumption and prices for Washington State, the rest of the United States and the rest of the world, as defined in the previous paragraphs. To calculate consumption for Washington wheat and Other wheat, we assume that half of Washington's wheat production is exported, and thus, corresponds to the consumption in the rest of the world. The other half of Washington's production is divided proportionally to population among Washington State and the rest of the United States.

Scenarios and Results

We model different scenarios to analyze the effects of the WSU wheat breeding programs and DNA fingerprinting. First we present the analysis of the WSU wheat breeding programs, followed by the analysis of the use of DNA fingerprinting technology. For the WSU wheat breeding programs simulation we analyze the changes in consumer, producer and total surplus due to a shift in the supply curve for producers using WSU wheat varieties. We assume that the shift in the supply curve is due to the yield improvement provided by using WSU wheat varieties. For the DNA fingerprinting simulation we analyze two scenarios. In the first scenario, consumers are willing to pay a 5 percent premium for Washington wheat. In the second scenario, the premium is 2 percent.

WSU Wheat Breeding Programs Simulation

We use GAMS (version 22.2) to solve for the equilibrium prices and quantities using the PATH solver for MCP models. With those results we calculate changes in consumer, producer, and total surplus (equations 10-12, 22 and 23) in each region and wheat class, the US and the rest of the world. Specifically, we use the supply and demand equations 13-16, 19-20 and the market clearing condition described in equations 17-18, and 21. We assume that the price elasticity of supply for the United States is 0.22 (DeVuyst et al (2001) as taken from Benirschka and Koo 1995), and for the rest of the world is 1 (Brennan, Godyn and Johnston 1989). The price elasticity of demand for the rest of the world is assumed to be -1.4 (Voon and Edwards 1992). The own- and cross-price elasticities of demand for the US wheat classes are presented in table A2 (Marsh 2005). We calculate a yield improvement of 1.27 percent for winter wheat (HRW and SWW), and 1.64 percent for spring wheat (HRS).[24] Table A3 contains quantity consumed and price per wheat class and region in million bushels and 2006 dollars per bushel, respectively; and table A4, quantity produced by wheat class and region in million bushels.

Changes in consumers' and total surplus are presented in table 1, and changes in producers' surplus in table 2. These changes in surplus are in million dollars, 2006. Tables 3 and 4 present surplus changes in 2006 dollars per acre. Our results suggest that producers using WSU varieties and consumers in all regions have increased surplus from the research-induced supply shift due to WSU wheat breeding programs. The specific increase in surplus depends on the region and level of production. The largest surplus increase for producers using WSU varieties, \$11 to \$13 million 2006 dollars per year, is observed for SWW in Washington State, which is the majority of the wheat grown in the Pacific Northwest. Surplus increases for producers using WSU varieties of SWW in Idaho range from \$2 to \$2.5 million 2006 dollars per year. In Oregon, producers using WSU varieties of SWW have increased surplus by \$0.7 to \$1.4 million 2006 dollars per year.

[24] Yield improvement was calculated as the marginal change in yield trend for spring and winter wheat in Washington State. We are currently working on calculating a more accurate measure of yield improvement due to the use of WSU varieties. Our results will be over or under estimated depending on if the actual yield improvement is smaller or larger than the numbers we are using in this draft.

Decrease in surplus to producers using other varieties range from $10 thousand to almost $4 million 2006 dollars per year for Washington, $10 thousand to almost $3 million 2006 dollars per year for Idaho, and less than $10 thousand to $3.5 million 2006 dollars per year for Oregon. Surplus for producers of SRW decreased by $500 to $900 thousand 2006 dollars per year, while surplus for producers of DUR increased by $400 to $860 thousand 2006 dollars per year due to the cross price effects among wheat classes. At an aggregate level, the effect on US producers depends on the specific year, with surplus increases in 2002, 2004 and 2005 of $40 to $600 thousand 2006 dollars per year, and surplus decreases in 2003 and 2006 of $10 to $450 thousand 2006 dollars per year. Surplus decrease for producers in the rest of the world range form $90 to $140 million 2006 dollars per year.

Changes in consumer surplus are positive in all regions, with the magnitude of the increase depending on the number of consumers in each region. Consumers in Washington have increased surplus by $51 to $63 thousand 2006 dollars per year, consumers in the United States by approximately $27 to $29 million 2006 dollars per year, while consumers in the rest of the world have increased surplus by approximately $99 to $160 million 2006 dollars.

The net effect in each region is always positive for Washington, the United States and the rest of the world. Increases in total surplus for Washington State range from approximately $11 to $14 million 2006 dollars per year. For the United States increase in total surplus ranges from $27 to $29 million 2006 dollars per year, and for the rest of the world, from $2 to $19 million 2006 dollars per year. However, the change in total surplus is always negative for Oregon, and depending on the year, it could be negative or positive for Idaho. The decrease in total surplus is small compared to the overall benefits, as represented in the total surplus changes for the United States as an aggregate. Specifically, decrease in total surplus for Oregon ranges from approximately $1 to $2 million 2006 dollars per year. Net effects for Idaho are smaller in magnitude, with increases of $170 thousand 2006 dollars for 2003 and decreases of $60 to $520 thousand 2006 dollars per year, for the other years.

To give some perspective about the magnitude of these surplus changes, we divide the change in surplus by the number of acres to get changes in surplus in 2006 dollars per acre. These results are reported in tables 3 and 4. Producers in Washington have increased surplus by approximately $4.5 to $6 2006 dollars per acre per year, producers in Idaho increased surplus by 3 cents per acre in 2003 and decreased surplus 15 to 50 cents per acre per year for the other years, while producers in Oregon have decreased surplus $1.7 to $2.6 2006 dollars per acre per year. On aggregate terms, producers in the United States have increased or decreased surplus in such small magnitudes, that in 2006 dollars per acre, the increase or decrease is very close to zero. Rest of the world producers have decreased surplus by approximately 20 to 30 cents per acre per year.

Total surplus changes for Washington represent increases of $4.75 to $6.14 2006 dollars per acre per year, for Idaho total surplus increases by 15 cents per acre for 2003, and decreases by 5 to 43 cents per acre per year for the other years. In the case of Oregon, there are net decreases of $1.35 to $2.18 2006 dollars per acre per year. Net effects for the United States as an aggregate are increases in surplus of approximately 50 cents per acre per year. Net effects for the rest of the world are quite small, with surplus increases of 0 to 4 cents per acre per year.

To formally evaluate the WSU wheat breeding programs it is important to compare to the costs incurred to fund these programs. As mentioned earlier, funds for the WSU wheat breeding programs come from a variety of sources including: state, federal, university and the Washington Wheat Commission. Given the public nature of these funds, it is a relevant policy question to ask if these funds are being used efficiently. We have presented a detailed analysis of the changes in surplus for several regions due to the use of varieties developed by WSU. Now we need to compare these net benefits with the cost of research. Unfortunately, we do not have enough accurate information to construct an investment variable, and obtain the rate of return or a benefit cost ratio.

The rough estimates of expenditures in WSU wheat research that we have correspond to 2003 to 2005, and range from approximately $3 to $8.5 million dollars. The cost data is not completely accurate, since it does not consider the lagged effect of wheat breeding research. It can take 7 to 12 years from the development to the marketing and adoption of a new wheat variety. However, these data give us a rough estimate to put the benefits obtained in perspective. The total change in surplus for Washington is approximately $4 to $6 dollars per acre per year and the research cost of WSU wheat breeding programs is approximately $1 to $3 dollars per acre per year. Thus, we obtain benefits of $2 to $4 dollars for each dollar invested in WSU wheat research.

Furthermore, the average profit for winter wheat is approximately $20 to $50 dollars per acre per year, while for spring wheat is approximately $0 to $30 dollars per acre per year. The increase in producer surplus for Washington represents about 10 to 20 percent of the average profit for winter wheat, and a 20 to 400 percent of the average profit for spring wheat. These numbers provide further evidence of the benefits for Washington state wheat producers of using the varieties developed by the WSU wheat breeding programs.

DNA Fingerprinting Simulation

As in the WSU wheat breeding programs simulation, we use GAMS (version 22.2) to solve for the equilibrium prices and quantities using the PATH solver for MCP models. For the DNA fingerprinting simulation we use the supply and demand equations 24 and 25, respectively, and the market clearing conditions described in equations 26 and 27. With those results we calculate changes in consumer, producer, and total surplus (equations 28 and 29). We consider two scenarios in this simulation. In the first one, we assume that a proportion of consumers in each region is willing to pay a 5 percent price premium for Washington wheat. [25] We assume a 2 percent price premium in the second scenario.[26] Results for the first scenario are presented in tables 5 and 6, and for the second scenario in tables 7 and 8. The data used for this simulation is reported in appendix tables A5 and A6. We assume that the price elasticity of supply for the United States is 0.22 (DeVuyst et al (2001) as taken from Benirschka and Koo 1995), and for the rest of the world is 1 (Brennan, Godyn and Johnston 1989). The price elasticity of demand for the rest of the world is assumed to be -1.4 (Voon and Edwards 1992). These elasticities are the same as in the previous simulation. The price elasticity of demand for the United States is assumed to be -0.059 (DeVuyst et al (2001) as taken from Benirschka and Koo 1995).

Results for the DNA fingerprinting simulation suggest great increases in surplus if producers in Washington are able to market their product in such way as to obtain a quality premium. At this point, we are not considering segregation costs independently. We assume that the price premium is on top of the extra costs incurred due to segregation. Producers in Washington could increase surplus by $1 to $3.3 billion 2006 dollars on average per year

[25] We assume that consumers value the certainty of knowing that they are receiving a higher quality wheat, and are willing to pay a 2 to 5 percent price premium for Washington wheat.

[26] These scenarios correspond to what wheat growers in Canada are currently receiving for wheat certificated using DNA fingerprinting (Geddes 2008).

depending on the specific scenario. Change in producers' surplus is zero for the rest of the United States and the rest of the world. Consumers willing to pay a premium for Washington wheat will increase surplus on average $3 to $7 million 2006 dollars per year for Washington, $140 to $360 million 2006 dollars per year for the rest of the United States, and $252 to $862 million 2006 dollars per year for the rest of the world. Consumers of wheat other than from Washington will have no changes in surplus.

The net effect is always positive, given that all changes in producers' and consumers' surplus are either positive or zero. Total surplus increases for Washington are on average $1.1 to $3.3 billion 2006 dollars per year, $140 to $360 million 2006 dollars per year for the rest of the United States, and $252 to $863 million 2006 dollars per year for the rest of the world. The increase in overall surplus for all regions is $1.5 to $4.5 billion 2006 dollars per year.

Unfortunately, at this point we do not have more information to make more realistic assumptions for the DNA fingerprinting simulation. It is important to note that we are not considering the potential decrease in the number of years it takes to develop and market a new wheat variety given the lack of information and data. However, we believe that the use of DNA fingerprinting technology could decrease the time and cost of developing and marketing a new wheat variety.

Conclusions

This article presents welfare effects of the WSU wheat breeding programs under a multi-product, multi-region, multi-variety model including spillover effects to Idaho and Oregon. We also draw some conclusions on the potential benefits to producers and consumers of the use of new technology like DNA fingerprinting that can potentially decrease the release time of new varieties, as well as provide a premium for producers similar to a certificate of origin. Given the specific characteristics of the different wheat classes and regions we believe that it is important to introduce these differences into the model to obtain more accurate results, since information is lost by aggregating all wheat classes and regions into one.

Overall, consumers in all regions and producers using WSU developed varieties have increased surplus from yield increases in wheat due to WSU wheat breeding programs. However, producers using non-WSU varieties, in the rest of the world and of other wheat classes have decreased surplus. It is important to note that this model is partial equilibrium and thus, we are holding constant all other potential yield increases due to technology or other wheat breeding programs to concentrate on the effect of WSU wheat breeding programs. Changes in total surplus are positive for all regions except for Oregon, and some years for Idaho. However, the surplus decreases in these two states are smaller relative to the increases in all other regions, and the net effects for United States and the rest of the world are positive.

We have analyzed an important question: if funds allocated to the WSU wheat breeding programs had a reasonable return. We do a rough comparison of the information we have regarding costs and benefits, and we find that for each dollar spent per acre we obtain an extra 2 to 4 dollars per acre. Unfortunately, we do not have enough accurate information to construct an investment variable, and obtain the rate of return or a benefit cost ratio. It is also important to consider the lagged effect that investment in research has. It takes 7 to 12 years to develop and market a new variety. Our results are important for Washington State University and policymakers in general, because they provide justification for the current funds allocated the wheat breeding programs. However, having accurate estimates for the cost of research is extremely important to reach any significant conclusions.

Regarding the DNA fingerprinting simulation, this is still work in progress given the lack of data and information to make accurate assumptions. Our results suggest that it is an attractive technology that can potentially provide great surplus increases for producers in Washington. More work is needed in this area to draw meaningful conclusions.

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Tables

Table 1: Consumers' and Total Surplus Changes

Region	2002	2003	2004	2005	2006
	Change in Consumers' Surplus [a]				
Washington	0.57	0.61	0.57	0.51	0.63
Idaho	0.13	0.14	0.13	0.12	0.14
Oregon	0.33	0.35	0.33	0.29	0.36
United States	27.14	28.73	26.84	26.84	29.27
Rest of the World	98.55	157.70	120.28	127.39	126.48
	Change in Total Surplus [a]				
Washington	11.35	14.14	13.97	11.66	13.56
Idaho	-0.25	0.17	-0.06	-0.52	-0.47
Oregon	-1.13	-1.83	-1.61	-1.67	-1.84
United States	27.18	28.28	27.43	26.94	29.26
Rest of the World	8.47	18.70	1.91	6.14	9.32

[a] Units are million 2006 dollars

Table 2: Producers' Surplus Changes [a]

Region	Class	Origin	2002	2003	2004	2005	2006
Washington	HRW	WSU	1.37	1.22	1.44	1.36	2.28
		Other	-0.02	-0.02	-0.01	-0.01	-0.04
	HRS	WSU	0.80	0.82	1.22	0.70	1.28
		Other	0.01	0.01	0.00	0.01	-0.01
	SWW	WSU	11.26	13.72	13.17	11.58	13.02
		Other	-2.63	-2.21	-2.42	-2.49	-3.61
	All	All	10.78	13.53	13.40	11.15	12.93
Idaho	HRW	WSU	0.00	0.00	0.00	0.00	0.00
		Other	-0.06	-0.07	-0.07	-0.07	-0.10
	HRS	WSU	0.00	0.00	0.12	0.13	0.30
		Other	0.02	0.03	0.01	0.02	-0.01
	SWW	WSU	2.52	2.54	2.44	1.99	1.95
		Other	-2.86	-2.47	-2.70	-2.70	-2.75
	All	All	-0.38	0.03	-0.19	-0.64	-0.61
Oregon	HRW	WSU	0.00	0.00	0.06	0.09	0.08
		Other	0.00	0.00	0.00	0.00	-0.01
	HRS	WSU	0.01	0.00	0.04	0.04	0.02
		Other	0.00	0.00	0.00	0.00	0.00
	SWW	WSU	1.17	1.36	1.44	0.91	0.71
		Other	-2.64	-3.54	-3.48	-2.99	-3.01
	All	All	-1.46	-2.18	-1.94	-1.96	-2.20
Other	HRW	All	-3.37	-4.28	-3.73	-3.91	-4.24
	HRS	All	0.39	0.71	0.32	0.50	-0.20
	SWW	All	-5.77	-8.23	-7.37	-5.38	-5.38
United States	SRW	All	-0.80	-0.89	-0.65	-0.53	-0.71
	DUR	All	0.65	0.86	0.74	0.86	0.42
	All	All	0.04	-0.45	0.59	0.10	-0.01
Rest of the World	All	All	-90.08	-139.00	-118.37	-121.25	-117.16

[a] Units are million 2006 dollars

Table 3: Consumers' and Total Surplus Changes

	2002	2003	2004	2005	2006
Region	**Change in Consumers' Surplus [a]**				
Washington	0.24	0.26	0.25	0.23	0.28
Idaho	0.12	0.12	0.11	0.10	0.12
Oregon	0.39	0.32	0.35	0.32	0.43
United States	0.45	0.46	0.45	0.47	0.51
Rest of the World	0.19	0.30	0.22	0.24	0.24
	Change in Total Surplus [a]				
Washington	4.75	6.03	6.14	5.24	6.09
Idaho	-0.23	0.15	-0.05	-0.43	-0.39
Oregon	-1.35	-1.69	-1.69	-1.87	-2.18
United States	0.45	0.46	0.46	0.47	0.51
Rest of the World	0.02	0.04	0.00	0.01	0.02

[a] Units are 2006 dollars per acre

Table 4: Producers' Surplus Changes [a]

Region	Class	Origin	2002	2003	2004	2005	2006
Washington	HRW	WSU	15.66	16.92	16.69	17.97	20.47
		Other	-0.35	-0.24	-0.21	-0.28	-0.44
	HRS	WSU	16.26	14.80	18.68	16.95	20.25
		Other	0.09	0.08	0.00	0.08	-0.05
	SWW	WSU	8.93	10.63	10.95	9.72	13.03
		Other	-5.92	-5.65	-5.30	-4.58	-5.58
	All	All	4.51	5.77	5.89	5.01	5.81
Idaho	HRW	WSU	0.00	0.00	0.00	0.00	0.00
		Other	-0.41	-0.35	-0.42	-0.40	-0.51
	HRS	WSU	0.00	0.00	28.57	27.66	29.41
		Other	0.07	0.10	0.04	0.10	-0.03
	SWW	WSU	11.85	13.08	14.70	13.22	15.23
		Other	-7.87	-6.94	-7.11	-6.21	-6.50
	All	All	-0.35	0.03	-0.16	-0.53	-0.51
Oregon	HRW	WSU	0.00	0.00	16.22	16.67	16.33
		Other	0.00	0.00	0.00	0.00	-0.65
	HRS	WSU	12.50	0.00	20.00	22.22	16.67
		Other	0.00	0.00	0.00	0.00	0.00
	SWW	WSU	6.47	8.35	9.96	8.86	10.52
		Other	-4.29	-4.43	-4.83	-4.17	-4.48
	All	All	-1.74	-2.02	-2.03	-2.19	-2.60
Other	HRW	All	-0.11	-0.13	-0.12	-0.13	-0.15
	HRS	All	0.03	0.06	0.03	0.04	-0.01
	SWW	All	-4.37	-4.06	-3.68	-2.99	-3.87
United States	SRW	All	-0.10	-0.11	-0.08	-0.09	-0.10
	DUR	All	0.22	0.30	0.29	0.31	0.22
	All	All	0.00	-0.01	0.01	0.00	0.00
Rest of the World	All	All	-0.17	-0.27	-0.22	-0.22	-0.22

[a] Units are 2006 dollars per acre

Table 5: Consumers' Surplus Changes with DNA Fingerprinting [a]
Scenario 1: 5% Price Premium for Washington Wheat

	Washington		Rest of the United States		Rest of the World	
Year	**Washington**	**Other**	**Washington**	**Other**	**Washington**	**Other**
1987	5.96	0	321	0	863	0
1988	8.99	0	484	0	1,118	0
1989	7.30	0	393	0	871	0
1990	6.76	0	339	0	760	0
1991	5.19	0	260	0	611	0
1992	6.40	0	321	0	732	0
1993	9.41	0	471	0	1,138	0
1994	7.60	0	381	0	888	0
1995	10.95	0	549	0	1,349	0
1996	11.68	0	585	0	1,312	0
1997	7.85	0	394	0	897	0
1998	5.94	0	297	0	766	0
1999	4.36	0	218	0	573	0
2000	6.35	0	297	0	792	0
2001	5.26	0	245	0	612	0
2002	6.86	0	319	0	795	0
2003	6.87	0	319	0	824	0
2004	6.44	0	298	0	713	0
2005	6.28	0	290	0	735	0
2006	7.91	0	362	0	909	0

[a] Units are million 2006 dollars

Table 6: Producers' and Total Surplus Changes with DNA Fingerprinting [a]
Scenario 1: 5% Price Premium for Washington Wheat

	Producers' Surplus			Total Surplus			
Year	**Washington**	**Rest of the United States**	**Rest of the World**	**Washington**	**Rest of the United States**	**Rest of the World**	**Overall**
1987	2,781	0	0	2,787	321	863	3,971
1988	4,264	0	0	4,273	484	1,118	5,874
1989	3,669	0	0	3,676	393	871	4,940
1990	3,365	0	0	3,371	339	760	4,470
1991	2,377	0	0	2,382	260	611	3,252
1992	3,066	0	0	3,072	321	732	4,125
1993	4,436	0	0	4,445	471	1,138	6,054
1994	3,406	0	0	3,413	381	888	4,683
1995	5,033	0	0	5,044	549	1,349	6,942
1996	5,542	0	0	5,554	585	1,312	7,452
1997	3,888	0	0	3,895	394	897	5,186
1998	2,825	0	0	2,831	297	766	3,894
1999	2,034	0	0	2,038	218	573	2,829
2000	2,752	0	0	2,759	297	792	3,848
2001	2,264	0	0	2,269	245	612	3,126
2002	2,781	0	0	2,788	319	795	3,902
2003	2,788	0	0	2,794	319	824	3,937
2004	2,873	0	0	2,879	298	713	3,891
2005	2,693	0	0	2,699	290	735	3,723
2006	3,231	0	0	3,239	362	909	4,509

[a] Units are million 2006 dollars

Table 7: Consumers' Surplus Changes with DNA Fingerprinting [a]
Scenario 2: 2% Price Premium for Washington Wheat

	Washington		Rest of the United States		Rest of the World	
Year	**Washington**	**Other**	**Washington**	**Other**	**Washington**	**Other**
1987	2.33	0	126	0	250	0
1988	3.52	0	190	0	325	0
1989	2.86	0	154	0	255	0
1990	2.65	0	133	0	224	0
1991	2.03	0	102	0	178	0
1992	2.51	0	126	0	215	0
1993	3.69	0	185	0	333	0
1994	2.98	0	149	0	258	0
1995	4.29	0	215	0	394	0
1996	4.58	0	230	0	385	0
1997	3.08	0	154	0	265	0
1998	2.33	0	117	0	225	0
1999	1.71	0	86	0	168	0
2000	2.49	0	116	0	232	0
2001	2.06	0	96	0	179	0
2002	2.69	0	125	0	230	0
2003	2.69	0	125	0	239	0
2004	2.53	0	117	0	210	0
2005	2.46	0	114	0	215	0
2006	3.10	0	142	0	264	0

[a] Units are million 2006 dollars

Table 8: Producers' and Total Surplus Changes with DNA Fingerprinting [a]
Scenario 2: 2% Price Premium for Washington Wheat

	Producers' Surplus			Total Surplus			
Year	Washington	Rest of the United States	Rest of the World	Washington	Rest of the United States	Rest of the World	Overall
1987	916	0	0	919	126	250	1,294
1988	1,404	0	0	1,408	190	325	1,922
1989	1,206	0	0	1,209	154	255	1,618
1990	1,104	0	0	1,106	133	224	1,464
1991	782	0	0	784	102	178	1,064
1992	1,007	0	0	1,009	126	215	1,350
1993	1,458	0	0	1,461	185	333	1,979
1994	1,121	0	0	1,124	149	258	1,532
1995	1,655	0	0	1,660	215	394	2,268
1996	1,821	0	0	1,825	230	385	2,440
1997	1,275	0	0	1,279	154	265	1,698
1998	928	0	0	930	117	225	1,272
1999	669	0	0	670	86	168	923
2000	905	0	0	907	116	232	1,255
2001	744	0	0	746	96	179	1,021
2002	916	0	0	919	125	230	1,274
2003	918	0	0	921	125	239	1,285
2004	943	0	0	946	117	210	1,273
2005	885	0	0	888	114	215	1,216
2006	1,064	0	0	1,067	142	264	1,473

[a] Units are million 2006 dollars

Appendix

Table A1: Number of Acres Planted by State, Wheat Class and Origin

State	Class	Origin	2002	2003	2004	2005	2006
		WSU	87,500	72,100	86,300	75,700	111,400
	HRW	Private	24,200	60,400	17,500	29,200	52,200
		Total	144,500	157,000	133,500	111,800	202,000
		WSU	49,200	55,400	65,300	41,300	63,200
Washington	HRS	Private	81,900	103,700	105,700	81,900	171,500
		Total	159,500	186,500	201,000	165,100	275,400
		WSU	1,261,283	1,290,583	1,203,017	1,191,450	999,517
	SWW	Private	140,783	143,500	174,333	186,700	155,600
		Total	1,705,500	1,681,500	1,659,500	1,735,000	1,647,000
		WSU	0	0	0	0	0
	HRW	Private	16,200	27,300	12,700	11,300	12,300
		Total	148,000	201,000	165,000	175,000	195,000
		WSU	0	0	4,200	4,700	10,200
Idaho	HRS	Private	16,200	27,300	12,700	11,300	12,300
		Total	148,000	201,000	165,000	175,000	195,000
		WSU	212,700	194,200	166,000	150,500	128,000
	SWW	Private	59,600	41,000	50,600	54,300	68,500
		Total	576,000	550,000	546,000	585,000	551,000
		WSU	0	0	3,700	5,400	4,900
	HRW	Private	0	3,400	0	0	6,700
		Total	4,200	8,200	4,600	9,400	20,400
		WSU	800	0	2,000	1,800	1,200
Oregon	HRS	Private	11,600	20,000	13,200	12,300	9,000
		Total	27,800	30,200	34,600	39,300	53,000
		WSU	180,733	162,883	144,533	102,700	67,517
	SWW	Private	1,400	2,500	24,900	4,200	17,400
		Total	795,800	961,800	865,400	820,400	739,500

Table A2: Own- and Cross-Price Elasticities of Demand [a]

	HRW	HRS	SRW	SWW	DUR
HRW	-0.864	1.522	-0.023	0.366	0.306
HRS	0.949	-1.712	-0.017	-0.373	-0.234
SRW	-0.009	-0.011	-0.028	0.024	0.071
SWW	0.066	-0.108	0.011	-0.036	-0.045
DUR	0.067	-0.082	0.04	-0.054	-0.118

[a] Source: Marsh (2005)

Table A3: Quantity Consumed and Price

	2002	**2003**	**2004**	**2005**	**2006**
Class / Region	**Quantity Consumed [a]**				
HRW	377.13	378.08	382.05	368.11	355.00
HRS	215.00	223.00	228.00	227.00	235.00
SRW	165.00	153.00	155.00	155.00	165.00
SWW	80.00	85.00	75.00	85.00	85.00
DUR	81.49	72.85	69.50	79.18	85.00
ROW	21068	20434	21224	21792	21537
	Price [b]				
HRW	4.75	4.54	4.36	4.70	5.44
HRS	5.01	4.80	4.97	5.14	5.41
SRW	3.81	4.01	3.21	3.23	3.98
SWW	4.43	4.33	4.19	3.69	4.87
DUR	4.76	5.82	5.97	6.17	6.49
ROW	5.46	5.28	4.90	5.01	5.92

[a] Units are million bushels
[b] Units are 2006 dollars / bushel

Table A4: Quantity Produced [a]

Class	Region	Origin	2002	2003	2004	2005	2006
HRW	Washington	WSU	5.08	4.69	5.78	5.07	7.35
		Other	3.31	5.52	3.16	2.42	5.98
	Idaho	WSU	0.00	0.00	0.00	0.00	0.00
		Other	11.40	16.08	14.85	15.93	15.02
	Oregon	WSU	0.00	0.00	0.23	0.33	0.26
		Other	0.00	0.00	0.05	0.24	0.82
	Other	All	600.55	1044.71	832.14	905.83	652.65
HRS	Washington	WSU	2.12	2.27	3.27	1.82	3.16
		Other	4.74	5.38	6.79	5.45	10.61
	Idaho	WSU	0.00	0.00	0.33	0.34	0.74
		Other	17.94	19.47	22.34	14.35	21.52
	Oregon	WSU	0.03	0.00	0.10	0.09	0.06
		Other	0.97	1.21	1.56	1.95	2.59
	Other	All	325.64	471.35	491.08	442.59	393.65
SWW	Washington	WSU	73.15	83.89	80.60	79.83	65.97
		Other	25.76	25.41	30.58	36.42	42.73
	Idaho	WSU	16.38	15.54	14.94	13.70	9.86
		Other	27.97	28.46	34.20	39.54	32.57
	Oregon	WSU	7.59	8.31	8.82	6.26	3.58
		Other	25.83	40.74	43.97	43.78	35.62
	Other	All	56.49	94.67	93.25	78.63	63.66
SRW	All	All	320.97	380.44	380.31	309.02	390.17
DUR	All	All	79.96	96.64	89.89	101.11	53.48
All	ROW	All	19277	18042	20915	20771	19974

[a] Units are million bushels

Table A5: Price and Quantity Produced (DNA Fingerprinting Simulation)

	Price [a]		Quantity Produced [b]		
Year	United States	Rest of the World	Washington	Rest of the United States	Rest of the World
1987	4.54	6.71	114	1993	16184
1988	6.35	8.10	125	1688	16375
1989	6.06	7.54	111	1926	17551
1990	4.03	5.16	150	2580	18875
1991	4.43	5.80	99	1882	17966
1992	4.65	6.00	120	2347	18168
1993	4.56	6.18	178	2219	18106
1994	4.70	6.07	134	2187	16901
1995	6.01	8.25	154	2029	17581
1996	5.53	6.97	183	2095	19128
1997	4.24	5.50	165	2316	19928
1998	3.27	4.74	157	2390	19128
1999	3.00	4.40	124	2171	19227
2000	3.06	4.56	165	2063	19136
2001	3.16	4.41	131	1816	19404
2002	4.00	5.46	130	1476	19277
2003	3.73	5.28	139	2205	18042
2004	3.63	4.90	144	2015	20915
2005	3.54	5.01	139	1965	20771
2006	4.27	5.92	140	1672	19974

[a] Units are 2006 dollars / bushel
[b] Units are million bushels

Table A6: Quantity Consumed [a] (DNA Fingerprinting Simulation)

	Washington		Rest of the United States		Rest of the World	
Year	Washington	Other	Washington	Other	Washington	Other
1987	1.04	18.95	56.10	1020	57.14	18330
1988	1.14	16.73	61.17	900	62.31	18050
1989	1.01	17.09	54.30	920	55.31	18462
1990	1.47	25.24	73.57	1265	75.04	18902
1991	0.96	21.18	48.34	1061	49.30	19080
1992	1.17	20.89	58.65	1047	59.82	18932
1993	1.74	22.52	87.05	1128	88.79	18966
1994	1.31	23.86	65.69	1196	67.00	18575
1995	1.50	20.80	75.38	1042	76.89	18798
1996	1.79	23.66	89.55	1186	91.34	19676
1997	1.62	22.98	80.94	1152	82.56	19876
1998	1.54	25.49	77.17	1277	78.71	19815
1999	1.21	24.22	60.86	1213	62.07	20136
2000	1.73	26.12	80.71	1221	82.44	20053
2001	1.38	23.67	64.29	1102	65.68	20242
2002	1.37	22.20	63.52	1032	64.89	21003
2003	1.47	23.71	68.20	1101	69.67	20364
2004	1.52	23.19	70.23	1074	71.75	21153
2005	1.48	22.97	68.17	1060	69.65	21722
2006	1.50	22.87	68.53	1048	70.03	21467

Note: Category Other represents wheat produced in a region other than Washington
[a] Units are million bushels

CHAPTER FOUR

FOOT-AND-MOUTH DISEASE AND THE MEXICAN CATTLE INDUSTRY

Introduction

Outbreaks of foot-and-mouth disease (FMD) are important economic events, distorting trade patterns world wide. The effects of FMD (e.g., trade bans, productivity losses, and inventory depopulation) can be extremely detrimental to a country, threatening food supplies, security, and safety. In 1946, Mexico suffered a FMD outbreak that lasted for 7 years and resulted in large losses in inventory and costs estimated over 250 million dollars (Shahan 1952). More recently, an FMD outbreak in the United Kingdom (UK) in 2001 caused losses of $3.6 to $11.6 billion US dollars (USD) (Mathews and Buzby 2001), with around 4 million animals where slaughtered. Losses from FMD outbreaks are not exclusive to producers. For instance, consumers can also be affected market responses and tourism can suffer because of travelling restrictions.

Country specific characteristics, such as dependence on exports, livestock-population demographics and management, disease-control policies, consumer reaction, and value of livestock, make it difficult to extrapolate the impacts of FMD in one country to another (Schoenbaum and Disney 2003). Because limited research exist for disease outbreaks in livestock (especially for Mexico), effective policy recommendations for industry and policy makers require careful analysis country by country. The intention of the current research is to uncover country specific observations and more general economic observations.

The objective of this study is to analyze the effects on trade (domestic and international) of a hypothetical FMD outbreak in the Mexican cattle industry, as well as producer and consumer responses using a bioeconomic model with dynamic effects. The specific characteristics of the Mexican cattle industry, like the differentiated production practices by region and low exports, make it particularly interesting, since most studies on the effects of FMD relate to countries with high exports. We specifically simulate the consequences of a hypothetical FMD outbreak under different mitigation scenarios. Our results will provide guidance when selecting different invasive species management policies. This study analyzes a relevant policy issue for the Mexican cattle industry. It is important for policy makers in Mexico to understand the potential impacts of an FMD outbreak and the consequences of the different mitigation policies to select the optimal one.

There have been different approaches taken to analyze disease outbreaks in the cattle industry. In the past, studies were mainly static, either partial equilibrium or input-output models (Garner and Lack 1995; Paarlberg and Lee 1998). However, this static approach is somewhat limited. Given the nature of cattle cycles and biological lags in production it is important to include dynamics when analyzing disease outbreaks in cattle. Jarvis (1974) and Rosen, Murphy, and Scheinkman (1994) emphasize the importance of incorporating dynamics and biology, specifically by analyzing the beef industry as a renewable resource. Some recent studies incorporate dynamics in the analysis of the cattle industry (Aadland 2004; Chavas 2000; Paarlberg et al. 2008; Zhao, Wahl, and Marsh 2006). Other authors also recognize the importance of spatial effects (Rich and Winter-Nelson 2007; Rich, Winter-Nelson and Brozović 2005a and 2005b). Specifically, these three articles analyze a particular area highly affected by FMD: South America, where the actions taken by one country have a high impact in neighboring countries.

Estimates of the effects of an FMD outbreak vary by country and author. Zhao, Wahl, and Marsh (2006) find that a depopulation rate of 60 to 70 percent with total welfare loss of $34 to $50 billion USD corresponds to a reasonable level of traceability for the United States. Their results indicate that it is beneficial to increase surveillance to minimize the costs associate with an FMD outbreak. Paarlberg et al. (2008) analyze the effects of a hypothetical FMD outbreak on the US agricultural sector. They assume that all agricultural sectors will recover after 16 quarters, with total losses to livestock related industries of $2.8 to $4.1 billion USD. Schoenbaum and Disney (2003) suggest that the best mitigation strategy depends on the speed of the spread of the virus and the demographics of the population. Wilson and Antón (2006) conclude that it is optimal and less restrictive to apply mitigation strategies first and then apply a small tariff if necessary. Rich and Winter-Nelson (2007) analyze South America, which has regions where FMD is endemic. They demonstrate the benefits using mitigation policies differentiated by region. Their results suggest that stamping out policies have the largest net present value over a 5 year period, but in the short term vaccination policies are more effective. All these studies provide evidence suggesting that the specific effects of an FMD outbreak and the optimal mitigation strategies are closely related to the specific characteristics of the industry. However, all of them suggest that investing in surveillance and mitigation strategies that could contain the outbreak faster are better, as long as the cost of implementing these measures does not outweigh the benefits.

This article complements the literature by analyzing the effects of a hypothetical FMD outbreak in the Mexican cattle industry. We develop a conceptual bioeconomic model that incorporates dynamic effects. This model allows us to simulate the effects of different mitigation strategies, including producer and consumer responses. To the best of our knowledge, this is the first study to formally analyze the effects of a hypothetical FMD outbreak in the

Mexican cattle industry. The model can be extended to analyze outbreaks for diseases other than FMD such as Bovine Spongiform Encephalopathy.

The rest of the article proceeds as follows. The next section provides some background on FMD and the Mexican cattle industry. We follow with the development of the theoretical framework. We next present the empirical application and data used for the analysis. Results are then presented. The article ends with some brief conclusions.

Background

FMD is a viral disease that affects cloven-hoofed ruminants, it is severe and highly contagious (APHIS 2007). Some of the symptoms of FMD are: fever, blister-like lesions, and erosions on the tongue, lips, mouth, teats and hooves (APHIS 2007). It is transmitted by respiratory aerosols and contact with infected animals (Center for Food Security and Public Health 2007). Even though most infected animals recover, and consumption of meat from infected animals is not considered a health hazard, FMD does severely affect meat and dairy production and trade status (Mathews and Buzby 2001). However, consumption of milk or dairy products from infected animals could infect humans (Mathews and Buzby 2001; SAGARPA 2004).

Mexico has been FMD free since 1954, when the last outbreak, from 1946 to 1954, was eradicated with a cost of $250 million, with over a million animals being killed (SAGARPA 2004). In 1947 the Mexican-American commission for FMD eradication was created and in 1952 the Mexican-American commission for FMD prevention was created. The Mexican policy for dealing with an FMD outbreak is similar to the policy in the United States. The policy consists of a complete stamp out that involves depopulation of affected herds, cleaning and sanitation of exposed premises, quarantining susceptible herds that could have been in contact with the infected herd, and depopulation of dangerous susceptible herds (SAGARPA 2004).

The Mexican cattle industry is highly differentiated by production region.[27] Most cattle are pasture-fed for regional consumption, with an increase in feedlot-finishing in the last years. Improvement in infrastructure and growing demand for grain-fed beef has increased trade among production regions and the implementation of feedlots. These new dynamics increase the potential for spreading the FMD virus through all production regions if there is an outbreak in any of the regions. The Secretariat of Agriculture, Livestock, Rural Development, Fisheries, and Food (SAGARPA) has developed several eradication and prevention programs for different diseases including FMD.

As mentioned earlier, FMD affects all stages in the cattle production: breeding, feeding and marketing. It is important to understand the particular characteristics of the Mexican cattle industry to be able to model each stage and obtain an accurate analysis of the effects of FMD on the Mexican cattle industry. Production in the Mexican cattle industry can be divided in two stages: breeding and feeding. The following description about the Mexican cattle industry comes from Cunningham (2006) and Peel (2008). In the breeding stage, calves are weaned after 7 to 10 months. At this point producers decide to keep some of the calves for breeding and send the rest to the feeding stage. About half of the female offspring are retained for breeding and half are sent to the feeding stage.

The feeding stage is usually divided into stocker and finishing systems. Stocker programs are further divided into intensive stocker and extensive stocker programs. The intensive stocker program is more expensive and lasts a shorter period of time than the extensive

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[27] The different production regions have different agro-climatic characteristics, management practices and the cattle have different genetics and biological productivity (Cunningham 2006).

stocker program. On average, the intensive stocker program costs $0.14 USD per head per day with a daily weight gain of 2.1 pounds and it lasts on average 120 days, depending on the production region. The extensive stocker program on average costs less than one US cent per head per day, with a daily weight gain of 0.65 pounds, and it lasts on average 373 days, depending on the region. About two thirds of the cattle going to stocker programs go into intensive stocker programs and one third into extensive stocker programs.

The finishing stage is further divided into four different systems: feeding lots for Northern style meat, feeding lots for Mexican style meat, supplemented grass finished, and grass finished. The majority of the cattle (about two thirds) go into grass finishing systems. Grass finishing systems are the least expensive ($0.02 USD per head per day) and require the longest amount of time (480 days), with a daily weight gain of 0.57 pounds. Feeding lots for Northern style meat are similar to US feedlots and are the most expensive ($1.54 USD per head per day), with an average daily weight gain of 3.15 pounds over 132 days. Approximately 15 percent of cattle go into this finishing system. Cattle fed for Mexican style meat (approximately 24 percent of cattle) go into similar feedlots as Northern style meat, but for fewer days (114 days on average, depending on the region). The supplemented grass finishing program consists on grass finishing with feed supplementation. This program is less expensive than feedlot finishing ($1.40 USD per head per day on average), lasts about 110 days (depending on the region), with an average daily weight gain of 1.81 pounds. A very small percentage of cattle go into this program.

The Mexican cattle industry main exports consist on calves and feeder cattle to the United States. Approximately 15 percent weaned calves are exported to the United States. On the import side, there are not significant imports of live cattle. When there are any imports of live cattle, these are mainly cull cows from the United States. However, there are some meat exports, mainly to the United States and mostly meat imports, mainly from the United States and Canada. In all, Mexico is a net importer of meat.

Theoretical Framework

The model is specified as a discrete time optimal control model linked to domestic and international markets. We start the model of the Mexican cattle industry by defining the breeding decision followed by the feeding decision. Then we present the demand and supply conditions, including domestic and international markets. Finally, we present the invasive species, FMD, dissemination. The overall conceptual framework we use follows Zhao, Wahl, and Marsh (2006), which is based on Aadland (2004) and Jarvis (1974). We extend and adapt this model to reflect the conditions in the Mexican cattle industry.

Breeding System

The breeding decision consists on a profit maximization of a representative decision maker based on the sum of the present values of all future profits. The choice variables are culling rate, imports and exports of breeding stocks. We constrain the maximization problem by the population dynamics observed in the Mexican cattle industry. We assume a perfectly competitive breeding market in inputs and outputs. The breeder's maximization problem is represented in equation 1, and the constraints in equations 2 to 5:

(1) $$\max_{\{E_t^j\},\{M_t^j\},\{KC_t^j\}} \left\{ \sum_{t=0}^{\infty} \beta^t E_0(\pi_t) \right\}$$

(2) $$K_{t+1}^{j+1} = (1-\delta^j)(K_t^j - KC_t^j + M_t^j - E_t^j)$$

(3) $B_t = \sum_{j=m}^{s} K_t^j$

(4) $K_{t+1}^0 = 0.5\theta B_t$

(5) $Moff_{t+1}^0 = 0.5\theta B_t$,

where β represents the time rate of preference.

We differentiate the breeding stock by age, *j*, over time, *t* (Aadland 2004; Zhao, Wahl, and Marsh 2006); *K*, *M* and *E* represent the number of domestic, imported and exported females for breeding, respectively; *KC* corresponds to the number of culled breeding females; δ refers to the death rate; *B* is the total number of female breeding animals; *m* represents the age at which a female can start breeding; and *s* the age at which a female stops breeding. Equations 4 and 5 refer to the female and male offspring, respectively, where θ corresponds to the weaning rate.

Profit is represented by:

(6) $\pi_t = R_t - TC_t$,

where *R* is the total revenue and *TC* is the total cost described in equations 7 and 8 below. Total revenue comes from meat sales, live exports, and salvage value of culled breeding animals.

(7) $R_t = P_t^0 (KC_t^0 + Moff_t^0) + \sum_{j=0}^{s} PE_t^j E_t^j + \sum_{j=1}^{s} P_t^j KC_t^j$,

where *P* represents the market price per head of culled animals, and *PE* the export price, both prices depend on time, *t*, and the age of the animals, *j*. We assume that animals retained for breeding become unsuitable for feeding and, consequently, assign a salvage value represented by *P* for animals of age *j* greater than or equal to one.

Total cost refers to maintenance, imports and a quadratic inventory adjustment (Zhao, Wahl, and Marsh 2006):

(8) $$TC_t = \sum_{j=0}^{s}\left(W_t^j K_t^j + PM_t^j M_t^j\right) + \frac{1}{2}MAC*\left(\sum_{j=0}^{s} KR_t^j - \sum_{j=0}^{s} KR_{t-1}^{s}\right)^2$$

(9) $$KR_t^j = K_t^j - KC_t^j + M_t^j - E_t^j ,$$

where *W* represents the maintenance cost per animal, *PM* corresponds to the import price, *MAC* refers to the marginal adjustment cost, and *KR* is the number of animals retained for breeding. The total change in inventories from the previous period is given by dK_t in equation 10.

(10) $$dK_t = \sum_{j=0}^{s} KR_t^j - \sum_{j=0}^{s} KR_{t-1}^j$$

The Kuhn-Tucker conditions for the breeder's profit maximization problem are:

(11) $$P_t^j \geq \psi_t(j) \quad \perp \quad KR_t^j \geq 0 ,$$

(12) $$PE_t^j \leq \psi_t(j) \quad \perp \quad E_t^j \geq 0$$

(13) $$PM_t^j \geq \psi_t(j) \quad \perp \quad M_t^j \geq 0$$

(14) $$KR_t^j + E_t^j \leq K_t^j + M_t^j$$

where

(15) $$\begin{aligned}\psi_t(j) = {} & \beta^{10-j}\left(\prod_{i=j}^{9}\left(1-\delta^i\right)\right)P_t^{10} - \sum_{k=j}^{9}\beta^{k-j}\left(\prod_{i=j}^{k-1}\left(1-\delta^i\right)\right)W^k \\ & + \sum_{k=j+1}^{10}\beta^{k-j}\left(\prod_{i=j}^{k-1}\left(1-\delta^i\right)\right)\theta^k P_t^0 - MAC*dK_t\end{aligned}$$

These conditions form the basis for the inventory component of the model.

Finally, we incorporate foreign supply and demand for breeding animals by age group. We specify total breeding animal imports and exports (*QM* and *QE*) as a function of the import and export price, respectively. Equations 16 and 17 present this relationship, where *fbs*(·) and *fbd*(·) represent the foreign supply and demand functions for breeding animals, respectively.

(16) $$QM_t^j = fbs^j\left(PM_t^j\right)$$

(17) $QE_t^j = fbd^j\left(PE_t^j\right)$

The specific system of equations to be solved for the number of breeding animals retained, imported and exported for an average producer in the Mexican cattle industry consists on equations 11 to 17.

Feeding System

Based on the discussion of the Mexican cattle industry, on the feeding stage we only model the intensive stocker and grass finishing programs, since about two thirds of the cattle go to these two programs. We assume that all calves not kept for breeding or exported will go through the intensive stocker program and then to the grass finishing program before going to slaughter and producing meat. The expected weight gain and cost are functions of the number of days on the program:

(18) $WT_d = w(d)$

(19) $C_{t,d} = c_t(d)$,

where *WT* is the feeder's carcass weight, and *C* is the feeding cost. The expected profit after *d* days on the program is defined as:

(20) $FP_{t,d} = PMeat_{t,d} WT_d - C_{t,d} - P_t^0$,

where *PMeat* represents the expected price of meat after *d* days on the program.

The feeder's problem is to choose the number of days that maximizes profit:

(21) $\max_d \left\{FP_{t,d}\right\}$ subject to (18), (19), and (20).

Assuming perfect competition, the maximum profit after the optimal number of days, d^*, will be zero and we can solve for the feeder price at time t:

(22) $P_t^0 = PMeat_{t,d*}WT_{d*} - C_{t,d*}$

Now we incorporate foreign supply and demand for feeders. We specify total feeders imports and exports (*FM* and *FE*) as a function of the feeder price. Equations 23 and 24 present this relationship, where *ffs*(·) and *ffd*(·) represent the foreign supply and demand functions for feeders, respectively:

(23) $FM_t^j = ffs^j\left(P_t^0\right)$

(24) $FE_t^j = ffd^j\left(P_t^0\right)$

The total domestic supply of fed meat is presented in the following equation:

(25) $S_{t+D} = WT_{d*}\prod_{j=0}^{\tau}\left(1-\delta^j\right)\left(KC_t^0 + Moff_t^0 + FM_t - FE_t\right),$

where D represents the optimal days on the program converted to the same time interval as t, in the nearest integer.

The finishing programs described here represent the connection between the breeding decisions and meat demand. The feeder price derived from the feeder's profit maximization is then used in the breeder's first order conditions to determine the market value for feeders and the capital value of breeding animals. In this model, the feeder price can be affected by the introduction of a hypothetical disease outbreak (for example, FMD) through the weight gain function and the optimal days on the program. The trade component to the model allows us to incorporate the effects of trade bans on live animals due to the disease outbreak.

Meat Supply and Demand, and Market Equilibrium

We consider both domestic and international markets to capture the full effects on trade of an FMD outbreak. Domestic demand (*D*) is assumed to be a function of the domestic price (feeder price, *PMeat*), and income (*IN*). Similarly, the export demand (*ME*) for Mexican meat and the import demand (*MM*) for foreign meat in Mexico are assumed to be a function of domestic price (*PMeat*) in Mexico and the corresponding income (*IN*). The demand equations are:

(26) $D_t = d(PMeat_t, IN_t)$

(27) $ME_t = ed(PMeat_t, IN_t)$

(28) $MM_t = md(PMeat_t, IN_t)$

We assume perfect competition in the meat market, and thus, the equilibrium price is obtained by solving the market equilibrium condition, where supply equals demand:

(29) $S_t + MM_t = D_t + ME_t$

Invasive Species Outbreak

We model the dissemination of FMD as a Markov-Chain State Transition process (Miller 1979; Berentsen, Dijkhuizen, and Oskam 1992; Mahul and Durand 2000; Rich and Winter-Nelson 2007). We assume that changes to the market and productivity parameters of infected animals are exogenous. Following Zhao, Wahl, and Marsh (2006), we allow the disease dissemination process to interact with cattle production and feeding decisions. We believe this assumption to be accurate, since an FMD outbreak will affect both cattle production and feeding decisions through cattle mortality, depopulation, increased birth rate, and lower weight gain.

After the FMD outbreak is introduced, we assume that in each period an animal changes from one state to another with some probability. These probabilities are based on the epidemiological characteristics of FMD and on the prevalence of the disease. We use a standard S-I-R (susceptible-infectious-removed) model of disease dissemination (Miller 1979; Rich and Winter-Nelson 2007), where we identify four states related to FMD: susceptible, infectious, immune or dead. Cattle inventories include all stocks of female and male animals available at time *t*. Let *INV* denote the inventory of category *k* at time *t*:

(30) $$INV_t^0 = K_t^0, \ldots, INV_t^s = K_t^s, \text{ and } INV_t^{s+1} = Moff_t^0$$

The probability of one susceptible animal in the *k*th inventory group becoming infectious is given by:

(31) $$\rho \frac{\sum_i \varepsilon_\tau^{k,i} I_\tau^i}{INV_t^k},$$

where τ denotes the time index for the dissemination process, *S* and *I* represent the number of susceptible and infectious individuals, respectively, in inventory *k* and ε corresponds to the number of effective contacts between animals of the *k*th and *i*th groups. The expected number of susceptible animals that will become infectious in group *k* is:

(32) $$\rho \frac{\sum_i \varepsilon_\tau^{k,i} I_\tau^i}{INV_t^k} S_\tau^k.$$

We characterize the FMD outbreak by the following system that captures the dynamics of the infectious herds:

(33) $$I_{\tau+1}^k = \rho \frac{\sum_i \varepsilon_\tau^{k,i} I_\tau^i}{INV_t^k} S_\tau^k + I_\tau^k - R_\tau^k,$$

where *R* denotes the number of animals that exit the infectious group, including recovered susceptible, recovered immune, and dead. To analyze the effects different government interventions and mitigation strategies we allow the epidemiological process to be influenced through the variable *R* that represents the mitigation and / or eradication effort. The other variable that we use to analyze mitigation strategies is ε, the number of effective contacts an infectious group can make. This variable can be modified to represent measures like restricting live animal movement and quarantine zones.

To generate the hypothetical FMD outbreak, we introduce the invasive species by a mechanism that initiates the dissemination process described by:

$$(34) \qquad I_0^k = \mu_t^k ,$$

where μ is a non-negative random variable representing the number of infectious animals introduced into the production system. We assume that μ follows a binomial distribution with the following density function:

$$(35) \qquad f\left(\mu_t^k\right) = \begin{pmatrix} H_t^k \\ \mu_t^k \end{pmatrix} p^{\mu_t^k} \left(1-p\right)^{H_t^k - \mu_t^k} ,$$

where p represents the probability that an infectious animal (host) is not successfully excluded from the production system, and H denotes the number of hosts introduced into the kth group.

The theoretical framework introduced in this section provides flexibility to analyze a series of possible mitigation strategies to provide guidance to policy makers. We integrate epidemiological and bioeconomic characteristics to build a dynamic model that represents the Mexican cattle industry. Furthermore, this model can be easily adapted to simulate hypothetical outbreaks of different diseases, not only FMD.

Empirical Application

In this section we construct an empirical application of a hypothetical FMD outbreak in the Mexican cattle industry. We discuss the various assumptions implemented in the empirical application of the theoretical framework described in the previous section. We use year 2002 as the base year for the FMD outbreak simulation. We choose 2002 given the trade distortions introduced by the BSE incidents in Canada and the United States in 2003. The relevant parameters of the model are presented in table 1 and the starting values and inventories are presented in table 2.

Breeding System

We consider that an annual system can describe accurately the breeding system, given the annual reproductive cycle of cattle. Following Aadland (2004), a heifer becomes productive at age 2 (*m* = 2 in equation 2), and the productive life ends at age 10 (*s* = 10 in equation 2). As mentioned in the description of the Mexican cattle industry, calves that are not retained for breeding will be kept in the breeding system for approximately one year. Thus, we specify additional inventories to track the number of female and mal yearlings:

(36) $$Fyg_t = (1 - \delta^0) KC^0_{t-1}$$

(37) $$Myg_t = (1 - \delta^0) Moff_{t-1}$$

The birth rate ($\theta = 0.5975$) and death rate ($\delta^0 = \delta^1 = 0.0675$, $\delta^{j>1} = 0.0325$) parameters, and the starting breeding inventories were obtained from Cunningham (2006). It should be noted that the birth rate in Mexico is quite low relative to the US birth rate of 0.85 (Zhao, Wahl, and Marsh 2006). This difference has important implications since it will take longer for the Mexican cattle industry to recover after an outbreak than for the US cattle industry.

Feeding System

We build the feeding system based on the information from Cunningham (2006) and Peel (2008) described in the Mexican cattle industry section. The total finishing cost (*AFC*) is calculated as the sum of the cost per day in intensive stocker production (*dcs* = \$0.14 USD per head) over the days in intensive stocker production (120 days on average) plus the sum of the daily cost in grass finishing systems (*dcg* = \$0.02 USD per head) over the optimal number of days in the feeding system, *d**, determined in the feeder's profit maximization.

Similarly, we calculate the finishing carcass weight (*FW*) as the initial carcass weight for intensive stocker (*iwts* = 169.36 pounds), plus the sum of the average daily gain in intensive stocker (*adgs* = 2.07 pounds) over 120 days, plus the sum of the average daily gain in grass finishing systems (*adgg* = 0.57 pounds) over the optimal number of days in the feeding system, *d**, determined in the feeder's profit maximization. The finishing cost, *AFW* (equation 38), and finishing weight, *FW* (equation 39), are used in the calculation of total meat supply and total profit.

(38) $$AFC = \sum_{d=1}^{120} dcs + \sum_{d=121}^{d*} dcg$$

(39) $$FW = iwts + \sum_{d=1}^{120} adgs + \sum_{d=121}^{d*} adgg$$

Meat Supply and Demand, and Market Equilibrium

We calculate the total supply of fed meat (*FMS*) as the number of feeders ready for slaughter (including live imports, *SrM*) multiplied times their finishing weight, *FW* (equation 40). The total supply of non-fed meat (*NFS*) is calculated by the number of culled breeding animals plus imports of culled cows (*CwM*) multiplied times the average slaughter weight (*ASW* = 475 pounds per head) (equation 41).

(40) $$FMS_t = \left(1-\delta^1\right)FW_{t-1}\left(Fyg_{t-1} + Myg_{t-1} + SrM_t\right)$$

(41) $$NFS_t = ASW * \left(\left(\sum_{j=1}^{m}\left(1-\delta^j\right)KC_{t-1}^j\right) + CwM\right)$$

We estimate the domestic demand for fed meat (equation 27) in log-log form using ordinary least squares (OLS) in STATA (version 9.2). We use annual data from 1980 to 2003 prior to the BSE incidents in Canada and the United States. As a proxy for income, we use gross domestic product (GDP). We deflate domestic price and GDP using the consumer price index (CPI) for Mexico. Domestic demand for meat was calculated as per capita meat consumption multiplied times population. Data for per capita meat consumption and domestic price were taken from Clark (2006). Population data were obtained from the US Census Bureau (US Census Bureau 2008). GDP data come from Mexico's National Institute for Statistics, Geography and Informatics (INEGI 2008). CPI data were obtained though the Bank of Mexico (Banco de Mexico 2008).

The price elasticity of demand obtained from the estimation is -0.91. Demand elasticity estimates for Mexico range from -0.55 to -1.1 in the literature (Clark 2006; Dong, Gould and Kaiser 2004; Golan, Perloff and Shen 2001). Demand for non-fed beef is usually less elastic (Zhao, Wahl, and Marsh 2006), thus, we use -0.5 as the non-fed price elasticity of demand. The demand equation for non-fed meat is given by:

(42) $$SV_t = C_1\left(NFS_t / ASW\right)^{-2},$$

where *SV* is the salvage value of culled breeding animals and C_1 is a constant term.

We calculate total profit (equation 43) as the sum of revenues from fed meat (*Rfm*) and non-fed meat (*Rnfm*) minus the feeding cost (*FC*), total breeding cost (*TBC*) and inventory adjustment cost, plus the breeding export price (*BrExP*) multiplied times the female yearling exports (*BrEx*) plus the male yearling exports (*MEx*) minus the breeder imports (*BrM*). The marginal adjustment cost (*MAC*) is calibrated to increase at the rate of \$0.001 USD per head when the change in the breeding stock increases by one. The revenue from fed meat (equation

44) consists on the market price at the optimal slaughter weight multiplied times the total supply of fed meat. The revenue from non-fed meat (equation 45) represents the salvage value times the total non-fed meat supply divided by the average slaughter weight. The feeding cost (equation 46) denotes the average feeding cost (*AFC*) in the last period multiplied times the number of feeders. The total breeding cost (equation 47) represents the average breeding cost (*ABC*) multiplied times the total number of breeding animals. *ABC* is $200 USD per year (Cunningham 2006).

(43) $$\pi_t = Rfm_t + Rnfm_t - FC_t - TBC_t - \frac{1}{2} MAC * \left(\sum_j KR_t^j - \sum_j KR_{t-1}^j \right)^2 + BrExP_t * \left(BrEx_t + MEx_t - BrM_t \right)$$

(44) $$Rfm_t = PMeat_t * FMS_t$$

(45) $$Rnfm_t = SV_t * NFS_t / ASW$$

(46) $$FC_t = AFC_{t-1} * \left(Fyg_{t-1} + Myg_{t-1} \right)$$

(47) $$TBC_t = ABC * \sum_{j=1}^{m} KR_{t-1}^j$$

For the international meat markets, we consider exports to the United States and imports from the United States and Canada. Meat exports from Mexico to the United States account for 80 to 99 percent of total meat exports from 1995 to 2003 (Global Trade Atlas). Meat imports from Canada and the United States represent 81 to 99 percent of Mexico's total meat imports from 1995 to 2003 (Global Trade Atlas). We estimate equations 27 and 28 in log-log form using OLS in STATA (version 9.2) to obtain the corresponding elasticities.

Data for the estimation were obtained from various sources. Monthly quantities exported and imported from January 1995 to November 2003 were obtained from the Global Trade Atlas. Domestic price in Mexico comes from the National System on Information and Market

Integration (SNIIM 2008). Domestic price in Mexico was deflated using Mexico's CPI for the import demand equations from the United States and Canada, and the US CPI for the export demand equation to the United States. CPI data for Mexico were obtained through Banco de Mexico (2008), and for the United States through the Bureau of Labor Statistics (BLS 2008). Data on exchange rate to transform price in the export demand equation to the United States to USD were obtained from the Pacific Exchange Rate Service, Sauder School of Business, University of British Columbia. Data on GDP for Mexico and the United States were obtained through INEGI (2008) and Bureau of Economic Analysis (BEA 2008), respectively. GDP for Mexico and the United States was also deflated using the corresponding CPI.

The estimated export demand elasticity for the United States is -0.58. The assumed supply elasticities from the United States and Canada are 0.05 and 1.2, respectively. The specific export demand and supply elasticities included in the model are constant elasticity equations given in equations 48 and 49. The market clearing condition is given in equation 50.

(48) $D_t^i = \alpha_i \left(P_t^i\right)^{ed_i}$, i = Mexico and United States

(49) $S_t^j = \beta_j \left(P_t^j\right)^{md_i}$, j = United States and Canada

(50) $\sum_i D_t^i = \sum_j S_t^j + DS_t$,

where α and β are constants calibrated to match the quantities and prices in year 2002, and DS represents domestic supply.

Invasive Species Outbreak

Following Schoenbaum and Disney (2003), we assume a 2 percent death rate in infected adult cattle, a 20 percent death rate in calves, and no other changes in productivity parameters due to the hypothetical FMD outbreak. We nest the dynamics of the dissemination process in weekly intervals. Following Zhao, Wahl, and Marsh (2006), we classify cattle groups in six states: susceptible, latent infectious, second week infectious, third week infectious, immune and dead.

After successful contact with infected animals, cattle become infectious for three weeks, where the average incubation period for FMD is three to eight weeks. Since during this period the animal can spread the virus without showing any symptoms, we call this stage latent infectious, which corresponds to the first week. After the first week, or incubation period, most animals will display foot and mouth lesions. Animals become immune after recovery, and while most of these animals still carry the virus, infection caused by contact with carriers is rare.

Data on dissemination rates for FMD are estimated based on results by Schoenbaum and Disney (2003). We assume that a herd makes 3.5 direct contacts with other herds per week, on average, with 80 percent effectiveness in transmitting the disease. The number of indirect contacts per week is assumed to be 35, with 50 percent being effective. One infectious herd can infect approximately 20 other herds per week. We use this dissemination rate for the first two weeks after the FMD outbreak is introduced. During this time there are no signs of the FMD outbreak visible to producers and government. Producers notice the outbreak after the second week. Mitigation strategies like movement control and quarantine measures are incorporated into the model at this stage. Starting at the third week, we assume that the dissemination rate decreases by half each week until the sixth week, when it reaches 2.5 percent. We assume a dissemination rate of 0.7 percent after the seventh week.

Results

We simulate welfare effects of different mitigation strategies that include several effort levels in tracing and surveillance. We assume that only infected herds are depopulated, 90 percent of the herds in the second and third infectious weeks are depopulated, when a herd is under surveillance, it will be depopulated in the first week if it becomes infectious, all beef exports and live cattle exports stop for three years, domestic demand decreases by 5 percent for three years, and there is no recurrence after eradication (Zhao, Wahl, and Marsh 2006).

We simulate different scenarios of the empirical model using GAMS (version 22.2). First we calibrate the model to represents the trade conditions in 2002 without an FMD outbreak. Next, we simulate different mitigation strategies. This way, we can calculate the welfare changes from the base case without the FMD outbreak to the different scenarios representing different mitigation strategies. We analyze seven scenarios, which correspond to a 30 to 90 percent (with increments of 10 percent) identification and depopulation rate of latent infectious herds. We assume that FMD is eradicated within one year. Thus, the FMD outbreak is equivalent to a one time shock to inventories, given the annual nature of production decisions. Results are presented in table 3.

Figure 1 represents the effect of a hypothetical FMD outbreak on beef price, assuming the different depopulation rates of latent infectious herds corresponding to each of the seven scenarios. Each depopulation rate represents a different percent loss in the total inventory, as summarized in table 3, due to both death and depopulation. We assume that the FMD outbreak is introduced in time period 20. We can observe the larger price effect given a larger reduction in cattle inventories. Even though demand decreases with the outbreak, the decrease in supply is larger, causing a large increase in price. After three years international markets re-open and demand increases, but since supply has not been able to recover we observe another price increase. As herds recover and cattle inventories increase, price decreases until it reaches equilibrium.

Depending on the specific scenario, the time required for price to return to equilibrium changes. As the depopulation rate increases the price after the introduction of the FMD outbreak decreases, and the number of time periods until prices revert back to equilibrium decreases as well. The number of time periods to get back to equilibrium is based on historical rates. However, this time could be adjusted by government intervention or industry innovations. For example, the government could implement a policy to increase the birth rate of cows, by providing information such as good birth management practices. Another option could be to subsidize producers to raise other types of cattle with higher birth rates. A third option could be to increase imports of breeding stock to help re-build the inventories faster. As mentioned earlier, the birth death in Mexico is 0.5975 compared to 0.85 in the United States, giving the Mexican cattle industry a disadvantage for recovery of inventories.

Changes in total, consumers' and producers' surplus as well as the percentage of total inventory depopulated and depopulation rate for each scenario are presented in table 3. In all scenarios, consumers are the ones with the largest surplus losses. The percentage of total inventory depopulated reaches a maximum of approximately 87 percent at a 30 percent depopulation rate (scenario 1). Welfare changes for this extreme scenario are negative for producers (2.25 billion USD) and consumers (28.71 billion USD), for a total decrease in surplus of 30.95 billion USD.

As the rate of depopulation of latent infectious herds increases from 30 percent, the percentage of total inventory depopulated decreases, given that the probability of becoming infectious decreases, as the number of latent infectious animals decreases. Consequently, welfare losses also decrease, and in some scenarios, changes in producers' surplus are positive. Welfare losses decrease as the depopulation rate increases, however, at a decreasing rate.

Results for the next two scenarios (40 and 50 percent depopulation rate) suggest that producers may lose $4.42 to $1.23 billion USD, while consumers may lose $22.57 to $10 billion USD with total surplus loss of $27 to $11.3 billion USD as the consequence of an FMD outbreak, respectively. These scenarios represent approximately 81 to 51 percent depopulation of total inventories, respectively.

We found that producers actually gain with a depopulation rate of 60 percent or higher. In these scenarios the increase in price combined with a more modest decrease in supply provide higher expected surplus for producers. Scenarios 4 and 5 correspond to a more reasonable level of traceability, with a depopulation rate of 60 and 70 percent, which translates into a 33 to 23 percent depopulation of total inventories, respectively. These two scenarios represent the largest gain to producers, although not the lowest loss in total surplus. The gain to producers is $2.38 to $2.42 billion USD, which is not enough to offset the loss to consumers of $7.77 to $5.88 billion USD, for a total surplus loss of $5.39 to $3.46, respectively for scenarios 4 and 5.

Finally, the last two scenarios represent depopulation rates of 80 and 90 percent, corresponding to 15.84 and 11.09 percent depopulation of total inventories. These two scenarios correspond to a quite optimistic level of traceability. Our results show that the gain to producers could be $1.96 to $1.45 billion USD, while losses to consumers are expected to be $4.48 to $3.55 billion USD, for a total surplus loss of $2.52 to $2.10 billion USD, respectively for scenarios 6 and 7.

Our results provide evidence suggesting the potential gains due to increased traceability and depopulation of latent infectious herds. However, it is important to consider the cost of implementing the necessary measures. Even though scenario 7 with the highest depopulation rate (90 percent) provides the lowest surplus loss, it may not be a feasible scenario due to the associated implementation costs. It should also be noted that this is not the scenario that provides the largest gains to producers. The optimal depopulation rate will be the one where marginal cost equals marginal benefit. At this point, we can say that the two more reasonable scenarios correspond to 4 and 5, that is, a 60 to 70 percent depopulation rate of the latent infectious herds.

It is interesting to compare our results with the outcome of the 1946 FMD outbreak in Mexico. The 1946 FMD outbreak in Mexico lasted for 7 years, over a million animals were killed, 52 million vaccinations were produced and applied, with estimated costs of 250 million USD (SAGARPA 2004; Shahan 1952). During the outbreak, the Mexican authorities received resources (monetary and human expertise) from the United States and Canada (Shahan 1952). Our results suggest that with a feasible depopulation rate of the latent infectious herds of 60 to 70 percent, we expect total welfare losses of $3.46 to $5.39 billion USD, and a 22.60 to 32.87 percent loss in total inventories, corresponding to 8 to 12 million animals relative to 2002 inventories.

Conclusions

This study analyzes a relevant policy issue for the Mexican cattle industry: the effects on trade (domestic and international) of a hypothetical FMD outbreak in the Mexican cattle industry, as well as producer and consumer responses. Our results provide guidance when selecting different invasive species management policies. In order to select the best mitigation strategy, it is important for policy makers to understand the potential impacts of an FMD outbreak and the consequences of the different mitigation policies.

This model incorporates dynamic effects to develop a conceptual bioeconomic model. Given the nature of cattle cycles and biological lags in production it is imperative to include dynamics when analyzing disease outbreaks in cattle. This model can be applied to different invasive species or disease outbreaks. Moreover, the model presented here can be further modified to represent other countries and / or industries.

Our results suggest that after a hypothetical FMD outbreak consumers are expected to lose the most, while with the appropriate depopulation rate, producers could lose or gain. Depending on the scenario considered, the expected loss in consumers' surplus is \$3.55 to \$28.71 billion USD, the expected loss in producers' surplus (scenarios 1 to 3) is \$1.23 to \$4.42 billion USD, while the expected gain in producers' surplus for scenarios 4 to 7 is \$1.45 to \$2.42 billion USD. Total surplus losses range from \$2.10 to \$30.95 billion USD. The percentage of total inventory depopulated ranges from approximately 11 to 87 percent.

Specifically for Mexico several observations are important. We find that welfare losses decrease as the depopulation rate of infected cattle increases, however, at a decreasing rate. With these results it seems that reasonable scenarios may be 4 and 5 corresponding to a 60 to 70 percent depopulation rate of latent infectious herds. Moreover, the increasing trend toward intensive feedlot operations could increase the likelihood of FMD spread should an outbreak occur. Finally, the optimal control scenario will depend on the point where marginal benefit equals marginal cost. Hence, it is important to consider the cost of implementing the necessary measures. To provide significant conclusions and valid policy recommendations we require accurate estimates of the cost of implementing the different traceability and depopulation rates.

In general terms, we find that as the depopulation rate of latent infectious herds increases, the percentage loss of total inventories decreases, and market disruptions including price shifts and the time to revert to equilibrium decrease as well. These results imply that it is beneficial to increase surveillance and information infrastructure, which is consistent with the previous literature. The focus of the majority of previous studies corresponds to countries highly dependent on exports. Our results show that even in countries where exports do not represent a significant part of the industry, the effects of invasive species outbreaks can be detrimental to the industry.

Further work for this study includes the traceability and depopulation implementation costs, a more accurate calibration of the model, and the incorporation of the feedlot finishing systems in the feeding part of the model. Having an estimate of the traceability and depopulation implementation costs will allow us to choose the optimal mitigation strategy to provide significant conclusions and valid policy recommendations. A more accurate calibration of the model will allow us to have a better representation of the effects of an FMD outbreak. Incorporating feedlot finishing systems into the model will provide a more truthful description of the Mexican cattle industry given that about one third of the cattle go through this system in the base year 2002.

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Tables

Table 1: Parameter Description and Values

Parameter	Description	Value	Units
Breeding			
δ^j	Death rate for age j>1	0.0325[a]	percentage
δ^j	Death rate for age j=0,1	0.0675[a]	percentage
θ	Birth rate	0.5975[a]	percentage
ABC	Average maintenance cost	200[a]	USD/year
MAC	Marginal adjustment cost coefficient	0.001[b]	USD/head
β	Time rate of preference	0.95[b]	percentage
Feeding			
dcs	Cost per day in intensive stocker production	0.14[a]	USD/head
dcg	Cost per day in grass finishing system	0.02[a]	USD/head
iwts	Initial carcass weight for intensive stocker	169.36[a]	pounds/head
adgs	Average daily gain in intensive stocker	2.07[a]	pounds/head
adgg	Average daily gain in grass finishing	0.57[a]	pounds/head
r	Interest rate	0.09[b]	percentage
Demand, Supply and Market Equilibrium			
ASW	Average slaughter weight	475.15[a]	pounds/head
ER	Exchange rate MXN-USD	9.66[c]	MXN/USD
Demand Elasticities (DE)			
MEX	Mexico domestic DE for beef	-0.91[d]	
US	US DE for Mexican beef	-0.5797[d]	
Supply Elasticities (SE)			
CAN	CAN SE for Mexican beef market	1.20[e]	
US	US SE for Mexican beef market	0.05[e]	
Constants			
α_{MEX}	MEX demand equation	4320.61[f]	
α_{US}	US demand equation	7.82[f]	
β_{CAN}	CAN supply equation	124[f]	
β_{US}	US supply equation	614[f]	
C_1	Demand equation for non-fed meat	110249[f]	

Sources: [a] Cunningham (2006); [b] Zhao, Wahl and Marsh (2006); [c] Pacific Exchange Rate Service; [d] estimated values; [e] assumed values; [f] calibrated values for 2002.

Table 2: Starting Values and Inventories [a]

Parameter	Description	Starting Value	Units
Pmeat	Meat price in Mexico	1.15	USD/pound
SV	Salvage value	645	USD/head
Moff	Male calves	4.49	million heads
Myg	Male yearlings	3.65	million heads
Fyg	Female yearlings	2.17	million heads
K^0	Females kept for breeding of age $j = 0$	2.18	million heads
K^1	Females kept for breeding of age $j = 1$	2.00	million heads
K^2	Females kept for breeding of age $j = 2$	1.85	million heads
K^3	Females kept for breeding of age $j = 3$	1.79	million heads
K^4	Females kept for breeding of age $j = 4$	1.73	million heads
K^5	Females kept for breeding of age $j = 5$	1.67	million heads
K^6	Females kept for breeding of age $j = 6$	1.61	million heads
K^7	Females kept for breeding of age $j = 7$	1.51	million heads
K^8	Females kept for breeding of age $j = 8$	1.49	million heads
K^9	Females kept for breeding of age $j = 9$	1.43	million heads
K^{10}	Females kept for breeding of age $j = 10$	0.00	million heads
KC^0	Culled females of age $j = 0$	2.31	million heads
KC^{10}	Culled females of age $j = 10$	1.39	million heads
SrM	Live bovine imports for slaughter	0.1505	million heads
BrM	Breeder imports	0.0391	million heads
CwM	Culled cows imports	0.0166	million heads
BrEx	Female yearling exports	0.078	million heads
MEx	Male yearling exports	0.541	million heads

[a] Calibrated values for 2002.

Table 3: Welfare Changes after an FMD Outbreak

Scenario	Depopulation Rate	Percentage of Total Inventory Depopulated	Change in Total Surplus [a]	Change in Consumers' Surplus [a]	Change in Producers' Surplus [a]
1	30%	86.79%	-30.95	-28.71	-2.25
2	40%	81.25%	-26.99	-22.57	-4.42
3	50%	50.71%	-11.29	-10.06	-1.23
4	60%	32.87%	-5.39	-7.77	2.38
5	70%	22.60%	-3.46	-5.88	2.42
6	80%	15.84%	-2.52	-4.48	1.96
7	90%	11.09%	-2.10	-3.55	1.45

[a] Units are billion USD

Figure

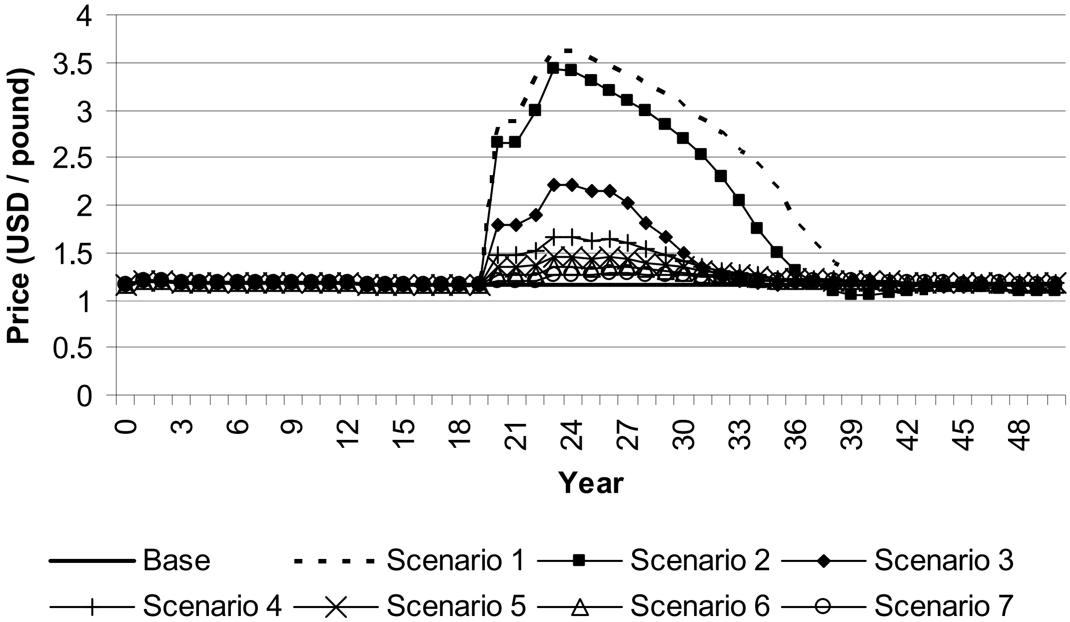

Figure 1: FMD Outbreak Effect on Beef Price