The Economic Implications of Invasive Species in International trade: the Chile-US fresh fruit market

Ricardo Diaz , Thomas Wahl, and Zishun Zhao[1]

Executive Summary

Background Information

Invasive species (IS) is the common name associated with "non-indigenous organisms" that pose a threat to the natural environment, agriculture, and human health. Increased trade between countries and the high diversity of environments among them have contributed to the risk of introduction of invasive species. Countries spend large amounts of resources attempting to stop invasive species before they enter their borders. However, the decisions are made with great uncertainty of the biological behavior of the pest and the potential economic loss to local agriculture, consumers, and the environment. Estimates of the monetary costs associated with biological invasions to the U.S. range from $5 to $140 billion per year. Under the World Trade Organization's Sanitary and Phytosanitary agreement, countries are required to use a common set of procedures for evaluating risks of contamination in internationally traded commodities. It also requires that quarantine systems reflect the expected benefits from risky trade and the level of risk that is acceptable for the society estimated scientifically. International trade of fresh fruit and vegetables involves high risk for unintentional introduction of new invasive species. U.S. trade of fruit and vegetables represent a value of more that $10 billion a year and more than 50% of fruit and vegetables consumed in the U.S. is imported. Chile is one of the major U.S. fresh fruit suppliers, with a value of more than $ 700 million a year. In order to evaluate the risk of a given invasive species, as well as the costs and benefits of taking a particular quarantine measure, a bio-economic fruit model based both on invasive species characteristics and the economic implications for both consumers and producers is developed. This model is used then to evaluate the cost and benefits of alternative invasive species management policies including off-shore control, control at the border, domestic monitoring and control, as well as eradication.

Recommendations:

It is recommended that ASCC Delegate:

Approve

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I. Introduction:

Invasive species (IS) is the common name associated with “non-indigenous organisms” that pose a threat to the natural environment, agriculture, or human health. In terms of natural resources, IS are considered to be second only to habitat loss in terms of risk of species extinction (www.biodiv.org). For agriculture, IS are usually associated with crop loss, poultry and livestock diseases and pests, etc. There are several examples of the devastating effects of invasive species. Grape Phylloxera (*Daktulosphaira vitifoliae*) is an aphid native to North America that between 1865 and 1875 caused the destruction of a large portion of the wine grape industry in Europe. The damage caused by this insect completely modified growing techniques and wine grape distribution around the world. This case has also an historical importance; the destructive effects of this pest brought several European countries together to the “International Convention on Measures to be taken against *Phylloxera vastatrix*” signed in 1878, the first international agreement on the spread of plant pests (Ebbel, 2003).

Other more recent examples of important IS are mad cow disease (bovine spongiform encephalopathy or BSE); and Mediterranean fruit fly or Medfly (*Ceratitis capitata*), considered one of the world’s most destructive agricultural pests.

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The Medfly, which originated in Africa, can attack and destroy more than 200 species of fruit crops, including citrus, cherries, apples, pears, peaches etc. Forestry, fishery, water use, and utilities are among other economic sectors from which impacts of IS have been reported (OTA, 1993).

Increased trade between countries and the high diversity of environments of those countries, and advances in transportation technologies, which allows for fast transoceanic delivery, have contributed to the risk of introduction of invasive species. Imports of goods such as fresh produce, animals, and timber and its derivates (such as solid wood packaging materials) represent important pathways for the introduction of IS. Increase in the rate of population growth and movement of people, as well as alteration of the environment, have been associated with an increase in the rate of introductions and risk associated with “biotic invaders” in the last 40 years (Pimentel et al, 2000). However, an extensively cited report by the United States Office of Technology Assessment (OTA) found no evidence that the rates of introduction of non-indigenous species (NIS) to the United States (U.S.) have increased in the last 50 years in any of the categories analyzed (terrestrial vertebrates, fish, mollusks, and plant pathogens) (OTA, 1993).

Despite the enormous benefits of most NIS, several cause great harm to countries’ economies. Even though only 16% of the NIS insects are considered to have a high impact as pests (OTA, 1993), countries spend large amounts of resources attempting to stop invasive species before they enter their borders. For example, in 1999, the United States (U.S.) spent an estimated $590 million to prevent and control IS, and the United Kingdom spent approximately $111 million in 2000 on animal and plant health (Mumford, 2002).

Extensive information about NIS is available, but it has been described as "widely scattered, sometimes obscure, and highly variable in quality and scientific rigor" (OTA, 1993). Rough assessments of the economic losses due to invasive species in the U.S. range from tens to hundreds of billions of dollars per year. Pimentel et al., (2000) estimated that NIS in the U.S. cause significant environmental damage and economic losses of approximately $137 billion per year. Specifically for agricultural crops, estimates of the potential losses associated with non-indigenous insects and mite pests reach US$16 billion each year in the U.S.; US$17 billion in India; US$8.5 billion in Brazil; US$1 billion in South Africa; US$960 million in the United Kingdom; and US$ 936 million in Australia (Pimentel et al., 2001).

Government agencies concerned with invasive species usually have two approaches to managing them: A) decisions are taken to stop potential invasive species before they enter the country (*ex-ante*) or B) decisions are made as to how to control invasive species after they have arrived (*ex-post*) (Maguire, 2001). In both of these scenarios, decisions are made with great uncertainty about the biological behavior of the pest and the potential economic loss to local agriculture and environment.

Ecosystems as well as the biological characteristics of the organisms will influence whether the NIS can become established and whether they can cause environmental and economic loss. Economic circumstances will also influence the probability of acquiring an organism by modifying both the pathways of introduction (passenger travel, import of goods, etc.) and the level and type of quarantine measures applied for a given species (Leung *et al*, 2002).

The World Trade Organization’s Sanitary and Phytosanitary agreement sets a series of procedures to analyze the risks of introduction of IS associated with internationally traded commodities. It also requires that quarantine systems consider both benefits and risks associated with international trade.

In order to more accurately evaluate the economic implication of the introduction of a given IS, the expected value of the changes in the producers’ surplus given in part by an increase in the production costs associated with the IS need to be assessed. The costs associated with the compliance of export and import protocols need to be addressed as well in order to estimate the total welfare effect that an IS has in international trade of fresh fruit. In this paper we propose a framework to evaluate the economic implications of a given IS in fruit production with a particular emphasis on the U.S.-Chile fresh fruit trade.

II. International Sanitary and Phytosanitary Measures:

Sanitary and Phytosanitary Measures are imposed by countries in order to ensure that food is safe for consumers, and to prevent the spread of pests and diseases among animals and plants. Under the World Trade Organization’s Sanitary and Phytosanitary (SPS) Agreement, countries are required to use a common set of procedures for evaluating risks of contamination in internationally traded commodities. It also requires that quarantine systems reflect the expected benefits from risky trade and the level of risk that is acceptable for the society estimated scientifically. The SPS Agreement’s main points are Basic Rights and Obligations; Harmonization of SPS Measures and Practices; Equivalence; Assessment of Risk and appropriate level of protection; Regionalization; Transparency; and Consultation and Dispute Resolution (http://www.wto.org).

First, the SPS Agreement recognizes the fundamental right of countries to protect the health and life of people, animals, and plants against pests, diseases, and other threats to health. However, SPS measures should not be applied in a manner that would represent a disguised restriction on international trade. The SPS Agreement also encourages countries to harmonize their SPS measures on as wide a basis as possible, by supporting their quarantine measures on relevant international standards. The international bodies mentioned in the agreement include the Codex Alimentarius Commission, the International Plant Protection Convention (IPPC), and the Office International des Epizooties (OIE) for food safety, plant health, and animal health standards respectively. Nevertheless, a country may choose not to use the existing international standard, if there is a scientific justification. Under the SPS Agreement, countries are required to accept the other countries' SPS measures as equivalent, even if these measures differ from their own, when the exporting country demonstrates that its measures achieve the importing country's desired level of quarantine security. The SPS Agreement continues to describe some basic terms related to risk analysis, including risk assessment, and its factors, as well as the economic consequences of the potential damage in terms of loss of production or sales in the event of the entry, establishment or spread of a pest or disease. The costs of control or eradication in the territory of the importing country, and the relative cost-effectiveness of alternative quarantine measures are also defined in the agreement. Under the SPS Agreement, countries are required to adopt import requirements based on the health conditions of the specific area or region where a plant or animal commodity originates. This introduces the concept of pest or disease free areas recognizing that pest and disease conditions may vary across a country and are dependent upon geographic and ecological differences as well as the effectiveness of sanitary or phytosanitary controls. The transparency rule is intended to give concerned countries an opportunity to provide relevant information in order to anticipate any changes in the SPS measures or regulatory actions that may affect trade. Finally, the SPS Agreement sets the procedures for dispute settlement, which begin with bilateral consultations and failing that, a complaining party may request intervention of a panel, which may seek recommendations and technical advice from relevant international organizations.

III. U.S. and Chile fresh fruit trade:

In the last 5 years the main U. S. exports to Chile were computer accessories, excavating machinery, and telecommunication equipment. Exports of agricultural products including fresh fruit represent only 4% of the $3 billion a year average total exported in the same period; U.S. exports of fresh fruit to Chile are not of economic importance. Figure 1 shows the evolution of the U.S.-Chile exports, imports and trade balance.

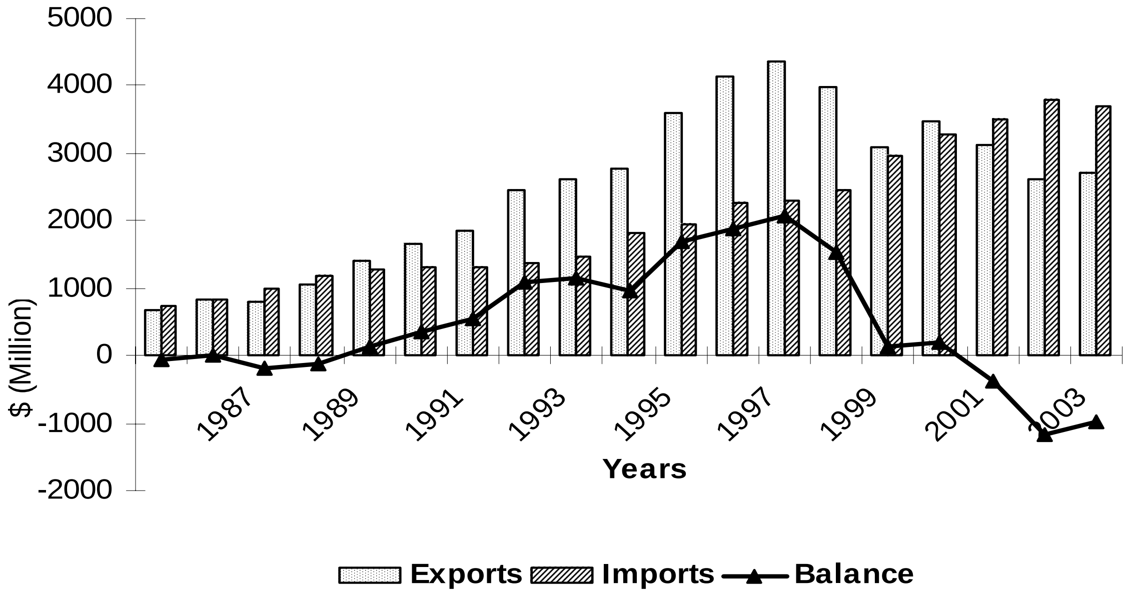

Figure 1: Evolution of the value of the U.S. exports and imports to and from Chile and the Trade Balance (U.S. Bureau of the Census trade data).

Chile is one of the leading fresh fruit exporters in the Southern Hemisphere. In 1997, for example, of total southern hemisphere exports, Chile exported 87% of the peaches, 76% of the table grapes, 35% of the apples, and 30% of the pears to the world market (Torres et al, 2001). Chile is also one of the main suppliers of fresh fruit for the U.S. market, supplying more than 20 different types of fresh fruits. Table grapes, apples, nectarines, and avocados are among the most important. In the last five years, U.S. imports from Chile represented an average value of $3.4 billion a year. Agricultural products corresponded to 30% of the total value imported. Chilean fruit production is mainly oriented toward the export market. U.S. fresh fruit imports represent 60% of the agricultural products and almost 20% of the total value imported from the country (U.S. Bureau of the Census). Figure 2 shows the evolution of the U.S. imports of fresh fruit from Chile.

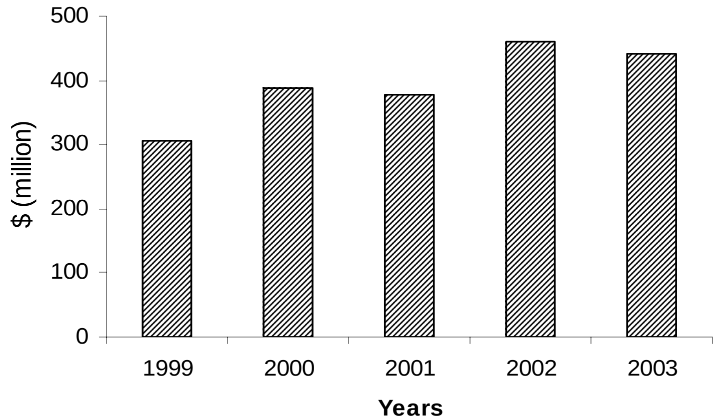

Figure 2. Evolution of the value of the U.S. imports of Chilean Fresh Fruit. Source: U.S. Bureau of the Census trade data.

Diversification of export markets have contributed to Chile's success as a leading fresh fruit exporter. The main export markets targeted by Chile are Western Europe, North America, Latin America, and the Middle and Far East (Torres et al, 2001). However, The North America Free Trade Area (NAFTA) represents the main market for agricultural products, accounting for more than 65% of the total Chilean agricultural exports (Odepa, 2004).

IV. Implications of IS on U.S. and Chile fresh fruit trade

Import of commodities such as agricultural produce, nursery stock, cut flowers and timber, unintentionally contaminated with insects and plant pathogens, is one of the main pathways for the introduction of new IS to the U.S (OTA, 1993). Given the high diversity of commodities that Chile provides to the U.S market, there is potential for the introduction of new IS.

Even though Chile is generally recognized as a country of “exceptional endemism” because of the high number of species exclusive to the territory (Kalin, 2004), many agricultural pests have been introduced with the unintended movement of plants and animals by humans. Chile’s geographical characteristics have allowed the country to remain somewhat free of many destructive agricultural pests. The Andes Mountain to the east, the Pacific Ocean to the west, and the Atacama Desert to the north have provided natural barriers to the introduction of many agricultural pests (Gonzalez, 1989). The fact that Chile in one of the few countries where the grape Phylloxera (*Daktulosphaira vitifoliae*) is not present, represents a clear example of the benefits of these geographical barriers. This aphid, native to North America, caused in the late 1800s the massive destruction of a large portion of the wine grape industry in Europe and changed the way wine grapes are grown today. Despite these natural barriers, the increase in trade between countries has enlarged the unintentional introduction of new non-indigenous species and invasive species have increased.

Most of the pests of “primary importance” for agriculture in Chile (Gonzalez, 1989) are not part of the regulated plant pest list of the U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service Aphis (APHIS). This list, published by APHIS, compiles pests frequently intercepted from imported commodities at U.S. ports of entry, and other pests identified by either APHIS or stakeholders as having the potential to cause serious economic or environmental damage in the U.S. In fact, most of the “primary pests” or pests with primary importance for fruit production in Chile are considered “cosmopolitan pests” (Gonzalez, 1989). A notable example is codling moth (*Cydia pomonella*), a native pest of Eurasia that today is a key pest affecting apple, European and Asian pear, Persian walnut, and Japanese plum production not only in Chile but also in the U.S. and other fruit producing countries in the world (Barnes et al.

1992). Even though codling moth is no longer included in the APHIS regulated plant pest list, it is the pest with the highest economic impact for apple production in the western United States and if not controlled, could destroy the entire industry. The cost of controlling codling moth was reported to be in the order of \$150 acre^{-1} year^{-1} (\$330 hectare^{-1} year^{-1}) under conventional production practices, assuming that there were five cover applications (Glover et al, 2002).

The APHIS regulated plant pest list includes several insect and mite species that are native to Chile. Most of these are not considered to be of primary importance for agriculture in Chile (Gonzalez, 1989). Out of the insects and mites native to Chile present in this list (*Leptoglossus chilensis*, *Megalometis chilensis*, and *Brevipalpus chilensis*), only the last one, *Brevipalpus chilensis,* also known as Chilean false red mite, has economic impact on Chilean fruit production and is subject to permanent control measures. Nevertheless, and given that the Chilean fresh fruit industry is mainly oriented to the export market, management practices need to be taken to ensure the fruit to be pest free, no matter the nature or origin of the pests.

Some authors believe that introduction of a new invasive species would have a greater chance of success when goods unintentionally contaminated with IS are traded among countries across latitude rather than south-north trade (Lattin and Oman, 1983). Sailer (1983) in his study about exotic pests in North American agriculture reported that South America accounted for only 1.7% of the exotic agricultural pests introduced to the U.S.. This can be explained by the counter seasonality of both hemispheres, implying that neither environmental conditions nor hosts would be readily available at the time of import. This would put Chile and other south hemisphere fruit producer countries in a very low risk category. However, great advances in storage technologies have allowed for big gaps between harvest time in the southern hemisphere and arrival time into the northern hemisphere importing country. Some fruit species, such as apples (*Malus domestica* Borkh.) and pears (*Pyrus communis* L.), can be stored for long periods of time, reaching the market when the environmental conditions may be appropriate for a successful adaptation of the pest. On the other hand, for other fruit species like raspberries (*Rubus spp.*) and cherries (*Prunus avium* L.), which have a considerably shorter storage period, this argument could make more sense. Import protocols need to take this consideration into account when defining quarantine measures for each particular fruit species.

The introduction of a new invasive species can affect fruit producers in three major ways; increasing production costs, decreasing yields, and reducing export returns to the grower. Production costs will be increased because the grower will need to undertake new measures to control the presence of the pest in the orchard. The occurrence of a given pest could also reduce the yields, because damaged fruit has to be eliminated. Finally, the detection of an IS in the importing country could cause the closure of this market, thus reducing the returns to the grower.

On the other hand allowing imports of fruit from a “risky” country will increase domestic fruit supply with the consequent benefits of lower prices for consumers (Roberts, 2000). Countries can use quarantine measures in order to reduce the risk of new IS introduction, and to ensure that food is safe for consumers. Quarantine measures can be taken either before the fruit gets out of the exporting country (i.e., prevention and preclearance practices) or in the importing country (i.e., border control, eradication, and management).

No single quarantine measure can completely eliminate the risk of introduction of a new IS. An economically feasible quarantine measure is one that reduces the expected possibility of successful invasion rather than the certainty of avoiding it (Mumford, 2002). Different quarantine measures have important economic and distribution effects not only for fruit growers but also for consumers and government agencies dealing with IS. The US quarantine on Mexican avocados (1990-1997) is a good example of the trade implications and distribution of the benefits from different quarantine measures (open and partial trade, and complete ban to the imports). It was estimated that partial trade (that was subsequently applied) produced a net gain of $2.5 billion per year compared to a complete ban in imports. Conversely, open trade would have had a net welfare of $32 billion without pest introduction and $13 billion with a theoretical pest introduction (Mumford, 2002).

Another important consideration in regard to the impacts of IS in international trade is the increasing importance of pests present in solid packaging wood materials (SPWM) (www.aphis.gov). Packaging materials have been usually considered externalities in most economic analyses of international trade. Evidence indicates that wooden shipping pallets and other types of packaging were the introduction pathway for the Asian longhorn beetle (*Anoplophora glabripennis*) to the U.S. and Western Europe from China. This pest may not be present in Chile, but given the high volume of goods being imported from Asia, government agencies should consider the risk and the implication of a successful introduction of the Asian longhorn beetle and the consequences for fresh fruit exports to U.S. and other important markets.

V. Conceptual Framework to analyze impacts of IS:

The introduction of a new IS into a country could have serious effects not only in production but also in consumption and exports of the affected commodity. As any other agricultural process, fruit production depends crucially on the biological features of the productive inventory. These biological features such as yield and final quality are highly susceptible to the impacts of an environmental change. The demands (domestic and foreign) for the final products could also be altered significantly when the quality of the final products changes. To fully analyze the impacts of an invasive species, we use a general equilibrium simulation model where the consumers maximize their utility and the producer maximizes profit with appropriate biological constraints. The conceptual modeling framework is designed to be general enough to accommodate most agricultural products. In Figure 3 the diagrammatic representation of the bioeconomic model of production and trade of fruit is shown.

The process of agricultural production consists of a productive population that evolves according to its biological features and the producer's decision to adjust the population. Thus, we specify our model in five parts: A) population mechanics, B) production functions, C) inventory updating, D) consumption decisions, and E) market clearing conditions. Rather than using one simulation for each fruit species, we group similar fruits together and simulate them simultaneously. We do this for two reasons—first, it is more likely that similar fruits would be susceptible to the impact of the same IS (pome fruit, citrus, etc.); second, we need to take into account the substitution effects to evaluate the impacts on consumer welfare.

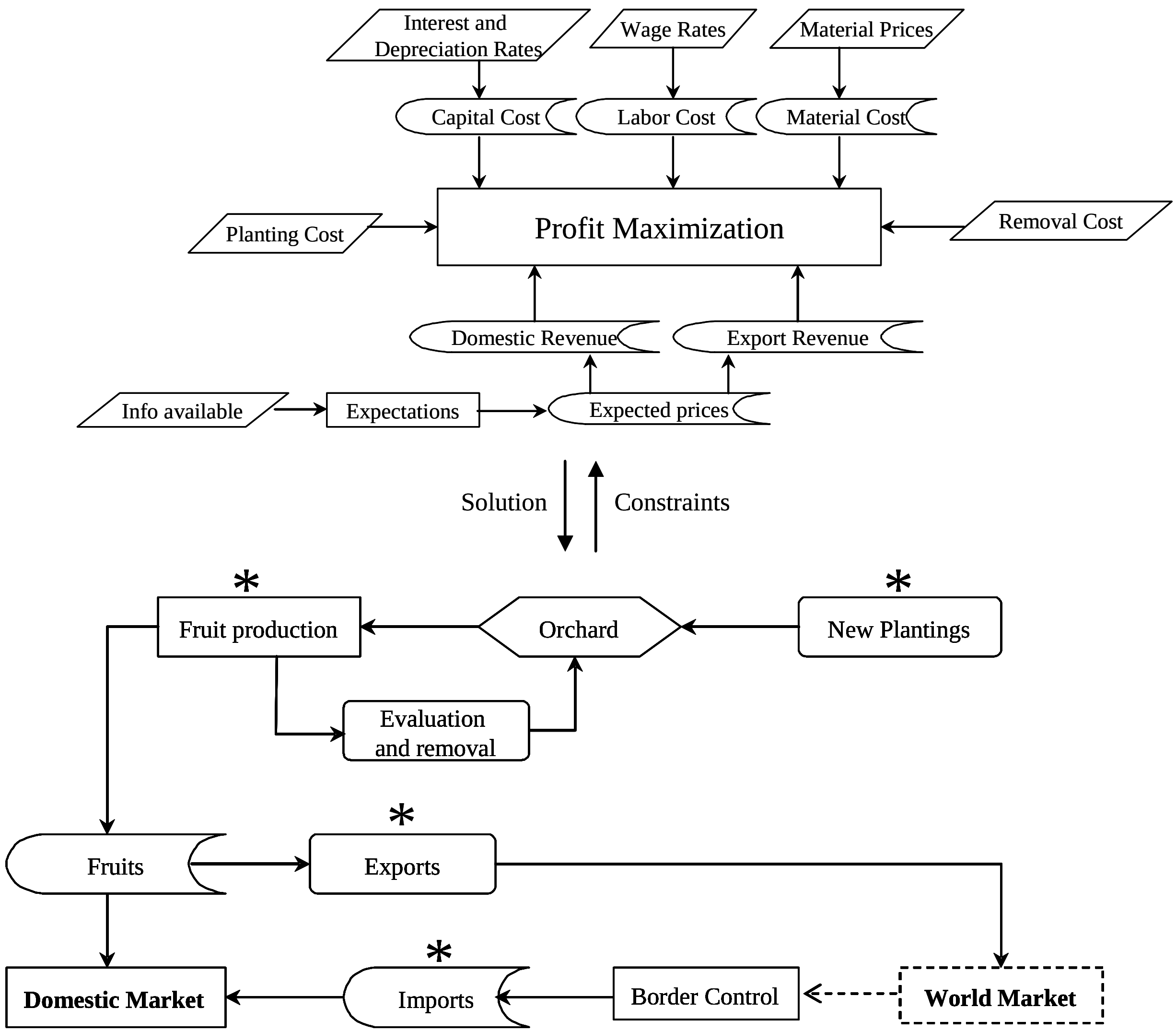

Figure 3. Diagrammatic representation of the bioeconomic model of production and trade of fresh fruit. Legend : ▱ exogenous variables ⊂ Endogenous variables ▭ Processes ▭ Choice variables ⬡ Inventory (stock variable) * indicates processes or variables where invasive species have influence.

Modeling Strategy:

For our analysis we assume that the fruit grower has one single objective: to maximize the total present value of all future profits. Under the grower's control are the addition to and subtraction from the productive stock of trees (orchard); effective management of production inputs, such as tree density at establishment of the orchard, fertilizer, pesticides, etc; and the selective administration of labor for the different orchard operations such as pruning, fruit thinning and harvest. We also assume that the grower's only source of revenue is from fruit sales. This is an important point because in fruit production there is a long lag between investment decision and revenue generation due to the time required for a tree (or group of trees) to reach its productive stage. Most fruit species will require a few years before they can start efficiently producing fruit. This time period will vary depending on several factors such as species, rootstocks, density, climate condition, etc. Thus, a long planning horizon and biological life cycle of the orchard is essential to the modeling framework.

Population Mechanics*:*

Orchards are usually divided into blocks of trees of the same age. Thus the stock of productive planting area is differentiated by tree ages. Each age group evolves according to the following equations:

(1.a) $K_{t+1}^{j+1} = (1-\alpha_t^j)K_t^j$

(1.b) $K_{t+1}^{0} = NP_{t+1}$

where K_t^j is the total area of age *j* trees at time *t*, α_t^j is the percentage to be removed from the stock of age *j* trees at time *t*, and NP_t is the area of newly planted trees. Any planting area that is not chosen to be removed during the current period progresses into the stock of the next age group.

Fruit Production and Supply:

We assume that fruit is the only product of the industry. Each year's fruit production is given by

$$(2) \qquad FP_t = \sum_{j=m}^{u} y^j K_t^j$$

where y^j is the yield per hectare of age *j* trees. While we, for now, treat the yields as exogenously given, they could vary depending on the history of productive inputs and their interaction with other external events such as climate. The events and the stream of inputs, varying in nature, could alter the time required to reach the productive stage, permanently damage the trees, or simply modify the final yield and quality of the fruit harvested for one or more periods.

The total production supplies are for both export and domestic markets. Since fruit production in Chile is mainly directed to the export market, the relative importance of the export market for this case will be higher. The domestic supply is then given by:

$$(3) \qquad SD_t = FP_t - E_t + M_t$$

where E_t and M_t are exports and imports respectively. Notice that E_t is a control variable but M_t is not.

Market Clearing Prices:

The Almost Ideal Demand System (AIDS) model is employed to define the fruit domestic demand because of its capability to generate exact welfare measures (compensated variation *CV* and equivalent variation *EV*). The system includes all fruits (assuming weak separability for the group “fruit”). With n commodities, the system can be thought of as a system of n equations in 2n+1 unknowns, including n prices, n demand quantities, and the group expenditure. When we hold the prices of all other fruits and the group expenditure as exogenously given, the number of unknowns is then reduced to n+1. With n equations, the domestic market-clearing price for the fruit under investigation and the demand for all other fruits can be solved in terms of the domestic supply of the fruit of interest. Thus, the domestic market-clearing price is given by

(4) $$Pd_t = f(SD_t).$$

If $EDf()$ denote a single equation export demand for the fruit, then exports are given by

(5) $$E_t = EDf(Pd_t).$$

Finally, if $FSf()$ denotes a single equation foreign supply of the fruit, imports are given by

(6) $$M_t = FSf(Pd_t + Tff_t)$$

where Tff_t is tariff or tariff equivalent trade barriers.

The Producer’s Problem:

The producer’s total profit equals the total revenue minus total cost. There are two sources of revenue; domestic sales and exports. If we assume that they are sold at the same price, the total revenue is just $Pd_t * FP_t$. Total cost consists of capital cost, labor cost, material cost, planting cost, and removal cost. Capital cost (KC), labor cost (LC), and material cost (MC) can be defined as the following

(7) $$KC_t = (r+d) * KR * \sum_{j=0}^{u} K_t^j$$

(8) $$LC_t = w_t * LR * \sum_{j=0}^{u} K_t^j$$

(9) $$MC_t = \left(\sum_{i=1}^{n} PM_t^i * MR^i \right) * \sum_{j=0}^{u} K_t^j$$

where KR, LR, and MR^i are the capital requirement, labor requirement, and i^{th} material requirement per hectare. *r*, *d*, and w_t are interest rate, depreciation rate, and wage rate respectively. Furthermore, let PC_t and RC_t denote the planting cost and removal cost respectively. Then the total cost is given by

(10) $$TC_t = KC_t + LC_t + MC_t + PC_t * NP_t + RC_t * \sum_{j=0}^{u} \alpha_t^j K_t^j \, .$$

Total profit at *t* is

(11) $$\pi_t = Pd_t * FP_t - TC_t \, .$$

The producer chooses the number of new plantings and the removal rates to maximize the total present value of all expected future profits subject to the constraint of the biological process.

(12) $$Max\left(E_0 \left[\sum_{t=1}^{\infty} \beta^t \pi_t \right] \right)$$ s.t. Biological Constraints

With a certain set of starting values for the stock variable and the solution from this problem, all future production and prices can be uniquely determined by the biological process.

Price Expectations:

The theoretical model could accommodate different expectation schemes, including naive expectations, rational expectations, bounded rational expectations, and adaptive expectations. Each of them has its advantages and disadvantages. Naive expectation is the simplest to implement, but tends to generate a corner solution. As a result production fluctuates dramatically. Rational expectations is relatively easy to implement and can stabilize supply, but the rational expectation assumptions are seldom supported by empirical work, especially in the case where significant delay is present between planning and actual revenue inflow. Adaptive expectations performs reasonably well in terms of mimicking the dynamics of market equilibrium and tends to have stable solution. Bounded rationality is another choice where market equilibrium can be mimicked reasonably well. The choice of the expectations scheme often depends on the particular characteristic of the production process under investigation and the actual behavior indicated by data and practice. In modeling fruit production, adaptive expectations is usually a good choice because of the long delay between planning and harvesting and the uncertainty about market price and production environment.

VI. Using the model to analyze the impacts of IS and benefits of alternative IS management policies:

An IS outbreak can change the production process as well as the market. On the production side, one or more of the exogenous costs of production can be increased dramatically, such as increased chemical use and/or increased requirements for other inputs. The outbreak will certainly change the yield. If we have the information as to how various input levels could affect yield, making some of the costs endogenous could help determine the optimal input level with the presence of the IS. On the market side, depending on the importing countries' policies, the outbreak could mean a complete or partial shutdown of exports. It could also mean an increase in export cost, in which case the exports also decrease due to increased foreign price. Lastly, if fruit quality is affected, it could mean that the higher end of the market is lost.

To complete the analysis, the speed of propagation and the scale of the outbreak need to be established. Several authors have recognized the uncertainties inherent in the bio-ecological nature in the estimation of a particular IS becoming successful in a new environment (Mack et al, 2000; Kareira, 1996; Maguire, 2001). These uncertainties can be reduced by the use of new technologies that are able to analyze bio-ecological data in order to assess the suitability of a habitat for the establishment and spread of potentially IS. Genetic Algorithm for Rule-set Prediction (GARP) (currently in beta version) is an artificial-intelligence application that translates the geographic locations of ecological features into a model of suitable and unsuitable habitats in ecological dimensions. The estimations and data generated using this modeling program can then be projected onto landscapes to identify areas that are suitable for a particular species to establish, succeed and spread (http://www.epa.gov/ord/htm/article3.htm). With all these pieces specified, the market equilibrium solution will generate the producer's surplus and the consumer's compensated variation and equivalent variation. The net impact of the IS can be measured by the change in the total social welfare caused by the outbreak.

The IS risk management policies include quarantine measures such as prevention (*ex-ante*) and controlling after establishment (*ex-post*) of a given IS. The benefit of controlling is straightforward. To model controlling after establishment, selected parameters in the model are systematically altered, which results in a new equilibrium welfare level. The prevention measures, without going into details of the methods, are designed to reduce the risk of an IS establishment. The benefit of prevention is then the reduction in the expected welfare loss under the implementation of the controlling policy due to the reduction in the probability of the IS establishment. Thus, an IS management scheme could be mapped into a social welfare value. The optimal scheme is the one that generates the highest welfare level.

VII. Concluding Remarks:

Invasive species cause great harm not only to agriculture but also the natural environment and human health. Countries spend large amount of resources attempting to stop IS before they enter their borders and controlling them after they have arrived. In either scenario the decisions are made with large biologic and economic uncertainties. WTO's sanitary and phytosanitary agreement set the common procedures for countries to analyze the risk of contamination in internationally traded commodities. In the case of plant pests, countries are encouraged to harmonize their quarantine measures based on international standards of the International Plant Protection Convention. Nevertheless, countries are allowed to use different standards if there is scientific justification.

Chile is one of the major suppliers of fresh fruit to the U.S. market as well as to other Asia-Pacific Economic Cooperation (APEC) members. Imports of unintentionally contaminated fresh fruit are important pathways for introduction of new IS. The wide variety of fruits supplied by Chile to the world market, and the diversity of environment among these countries represent potential risks for the introduction of new IS. Most of Chile's native insects and mites considered of quarantine concern for the U.S. are not pests of major importance for the country's agriculture. Nevertheless, the presence in the country of "cosmopolitan pests" such as codling moth, and the high pressure for pest introduction from neighbor countries, increases the risk of introduction of new IS to Chile's fresh fruit importing countries.

Trade liberalizing policies have multiple benefits including increase of the countries' population welfare. However, introductions of new IS can harm both producers and consumers, counteracting these benefits. Increase of production costs, decreases in yield, quality, and export returns for the fruit produced are the major ways producers are affected. On the other hand allowing imports from a "risky country" increases consumers' surplus by the reduction of the world price. Different quarantine measures have important economic and distributional effects.

The conceptual framework for the analysis of the impacts of IS is a general equilibrium model where consumers maximize utility and the producers maximize profit with appropriate biological constraints. The use of new technologies such as Generic Algorithm for Rule-set Prediction would reduce the uncertainties associated with the bio-ecological nature of the estimation of IS introduction, establishment and spread. Using the model proposed, the market equilibrium solution could generate producer's and consumers' surplus, and the impact of the new IS can be measured by expected changes in the total social welfare produced by alternative quarantine measures adopted by country. This information could be used by countries to evaluate and eventually change their current quarantine measures in order to meet their desired level of security, using the scientific approach required by the WTO SPS agreement.

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