Risk Factors for Invasive Pest Introductions in Commodity Imports: Theory and Empirical Evidence

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Abstract

Expanded world trade carries with it increased risks of invasions of exotic species and thus increased risks of ecological and economic damage. In the face of such risks, expansion of trade depends critically on the ability to detect unintended introductions of organisms in import shipments and determine whether those introductions are safe as is, safe after appropriate treatment, or unsafe even after treatment. This paper investigates factors associated with greater incremental risk of invasive pest introductions. It develops a conceptual framework based on the production-theoretic notion that invasive pests, like other forms of pollution, can be viewed as an input (or joint output) that serves to lower the cost of producing a commodity. In equilibrium, the prevalence of invasive pests in import shipments depends on production conditions and technology in the exporting country, commodity value and volume, and tariff rates. This conceptual framework suggests that the equilibrium rate at which invasive pests are present in import shipments will vary by commodity, country of origin, value, volume, and season as well as by regulatory factors such as whether pests that may be present in shipments of a commodity are treatable. These results are used to specify an econometric model of factors associated with heightened risk of invasive pest introductions. The parameters of the model are estimated using data from surveillance screening of fruit and vegetable imports into the US during fiscal years 2005-2007. The estimated parameters of the model are consistent with the predictions of the theoretical model. We use them to identify commodities and regions of origin of significantly high and low risk of invasive species introductions.

Introduction

International trade in commodities is widely recognized as one of the most important pathways for the introduction of invasive pests (Office of Technology Assessment 1993, National Research Council 2002). The risk of exotic pest invasions is a growing problem, due largely to the expansion of world trade. Trade always carries with it the risk that exotic organisms present in commodities themselves, in packing materials, or in transport equipment could be introduced into domestic environments. Once arrived, some of those organisms can establish themselves and some that establish themselves will go on to cause significant ecological and economic damage. The challenge from these exotic invaders has grown as trade has grown over time, both because the volume of introductions has grown along with trade and because the diversity of the organisms that arrive has increased as the countries with whom we trade have gotten more diverse.

Screening of import shipments is one of the main methods the US utilizes to prevent introductions of harmful exotic organisms. All plant materials entering the US (including packing materials in addition to fruits, vegetables, cut flowers, bulbs, seeds, cuttings, and other imports) are subject to inspection for potential invasive pest organisms. Shipments in which certain invasive pests are detected are allowed to enter the US only after treatment by fumigation, exposure to cold, or similar methods. Shipments in which certain other pests are detected are not allowed to enter the US under any circumstances and must thus be shipped elsewhere or destroyed. In either case, detection of invasive pest organisms imposes a cost on importers.

This paper conducts theoretical and empirical investigations of economic incentives and determinants of the risk of invasive pest introductions to the US through trade in fruits and vegetables.

We begin with a theoretical examination of the characteristics of equilibrium in import markets as a means of characterizing risk factors for invasive pest introductions, with particular emphasis on differences between treatable and non-treatable pests and the impacts of alternative regulatory regimes. In contrast to previous literature (McAusland and Costello 2004, Margolis, Shogren and Fischer 2005), we assume that tariffs and sanitary-phytosanitary (SPS) regulations are negotiated separately, so that tariffs are set without consideration of the threat of invasive species introductions. Also in contrast the previous literature, we focus on the inspection of individual cargoes that constitute small shares of the overall market, so that price effects (which play prominent roles in previous analyses) are negligible.

We use our theoretical framework to specify an econometric model in order to investigate empirically risk factors for invasive species introductions in import shipments of fruits and vegetables using data from routine surveillance screening conducted by the Animal and Plant Health Service of the US Department of Agriculture (APHIS). To our knowledge, there is no research that examines risk factors for invasive species introductions empirically using comprehensive pest interception and trade data for the United States. McCullough et al. (2006) present descriptive statistics on interceptions of invasive plant pests at US ports and border crossings derived from APHIS surveillance data for the period 1984-2000, including some cross-tabulations of taxa against region of origin, but do not attempt a more systematic (i.e., multivariate) decomposition of risk factors. Work et al. (2005) use data from the Agricultural Quarantine Inspection Monitoring program (AQIM) to estimate the number of invasive pest arrivals as a function of the number of shipments for refrigerated and non-refrigerated maritime cargo, air cargo, and cargo transported overland across the US-Mexico border. They, too, do not attempt a more systematic decomposition of risk factors. Moreover, the AQIM data they use cover only a subsample of shipments, while the APHIS surveillance data take samples from almost all commodity shipments. Costello et al. (2007) conduct a retrospective study of risks of introductions of aquatic invasive species by ocean vessels into San Francisco Bay during the period 1856-1994. They estimate those risks by applying an integrated likelihood approach to data from a study of invasive species introductions into the Bay combined with data on cumulative maritime imports by country of origin. Their analysis focuses on the relation between overall trade volumes and invasive species discoveries. Their data are sufficient to allow them to distinguish relative risks of imports from broad regions (e.g., Atlantic/Mediterranean, West Pacific, Indian Ocean) but not sufficient to distinguish relative risks by commodity. Moreover, their results are limited to aquatic invasives in San Francisco Bay.

Screening for Invasive Pests in Import Shipments

APHIS regulates imports of plants, plant materials, soils, biological control organisms, animals, and packaging materials under the authority of Plant Protection Act of 2000 (PPA). This act consolidated and harmonized 11 earlier statutes governing SPS regulations, including the Plant Quarantine Act (first enacted in 1912), the Plant Pest Act (first enacted in 1957), and the Federal Noxious Weed Act (enacted in 1974). The PPA gives APHIS the authority to inspect all incoming import shipments containing perishable materials (including packing materials) for potentially harmful exotic organisms, including plant and animal pests, weeds, and diseases. Actual performance of inspections was delegated to Customs and Border Protection (CBP) with the establishment of the Department of Homeland Security in 2003.

Between 1984 and 2000 approximately 750,000 nonindigenous pests comprising over 2,300 species were intercepted in baggage or cargo by APHIS inspectors at 160 points of entry into the U.S. Among these were over 565,000 insects, 6,000 mites, 11,500 mollusks, 440 nematodes, 95,840 pathogens and 50,000 weeds. About 22% of the pests originated in Central or South America, 18% from the Caribbean, 16% from Mexico, 16% from Asia, 9% each from Europe and the Pacific (excluding Asia), with the bulk of the remainder from Africa and the Middle East (McCullough et al. 2006).

When organisms are detected, CBP puts the shipment on hold. Samples of the organisms and the host material in which they were found are brought to APHIS identifiers housed in each port of entry, who make initial identifications whenever possible. Identifications are then used to determine quarantine status. There are two general types of quarantine status. Cargoes in which no exotic organisms have been detected or in which organisms detected are known to pose no risk of harm are considered *non-actionable* and are allowed to enter the US untreated. Cargoes in which exotic organisms are detected that do pose risk of harm are considered *actionable*. If the potential pest can be eradicated by fumigation, exposure to cold, or other forms of treatment then the cargo is allowed to enter the US after suitable treatment (including storage conditions such as extreme cold while in transit). If no reliable treatment methods are available then cargoes with actionable pests are not allowed to enter the US; they may be diverted to other countries or destroyed, at the discretion of the shipper.

Equilibrium Invasive Species Introductions: Theory

In keeping with our data and empirical investigation, we model the decision processes of an export firm sending a single shipment of a commodity and inspectors examining that shipment. We focus on the case where all cargoes in which invasive pests are detected are allowed to enter the importing country after treatment. During fiscal years 2005-2007, for instance, such cases accounted for 58% of shipments in which invasive pests were detected.

The game involves the following sequence of moves. The exporter moves first, choosing output y and infestation level q to maximize profit given the price in the importing country p, the importing country tariff τ, and the expected costs of treatment and any losses from delivery delays and quality degradation due to treatment (ky) incurred when invasive pests are discovered in the shipment, which occurs with probability ϕ(q,y,i), where i denotes the importing country's inspection strategy:

(1) $$\max_{y,q}[p - k\phi(q,y;i) - \tau]y - C(q,y)$$

Inspection intensity can be varied in a number of ways, including pulling a larger or small number of samples from a shipment, pulling samples from the interior of the cargo rather than from more easily accessible locations, or spending more time examining each sample. We assume that the exporting country treats the importing country's inspection strategy as given.

The probability of detection $\phi(q,y,i)$ is increasing in all three arguments. We assume also that it is concave in all three arguments, as is the case for the distributions most commonly used to devise sampling strategies (e.g., those based on binomial or Poisson approximations) for enforcing SPS regulations internationally in the case where i denotes the number of samples drawn or share of the shipment sampled (Venette et al. 2002, International Plant Protection Convention 2008). The signs of the cross-partial derivatives ϕ_{iq}, ϕ_{yq}, ϕ_{iy} (subscripts denote derivatives throughout this paper) are indeterminate and depend on the relative magnitudes of q, y, and i. If ϕ is well approximated by a Poisson, for instance, all three cross-partials are negative (positive) when $iy > (<) 1/q$; since infestation rates are typically low (the average in our sample is 3.2% of shipments), these cross-partial derivatives are likely to be negative when shipment volume is large and positive when shipment volume is small. A similar result holds for ϕ_{iq} and ϕ_{yq} when ϕ is well approximated by a binomial, but $\phi_{iy} < 0$ for all reasonable infestation rates (specifically, $q < 0.632$).

Following Lichtenberg (2002), we model infestation and output as joint products. Infestation reduces the total and marginal costs of producing output, C_q, $C_{yq} < 0$. Production cost is convex, which requires $C_{qq} > 0$ (diminishing marginal productivity of infestation).

In the second stage, the importing country chooses the intensity with which to inspect each shipment to inspect to minimize the costs of damage from pest invasions plus expenditures on inspection, assumed increasing in inspection intensity i and shipment volume y, taking the shipment volume and infestation rates as given:

(2) $$\min_i H[z(i,q,y)] + E(i,y)\,.$$

Here η denotes the probability that treatment eliminates invasives (equivalently, the share of invasives killed by treatment) and $z(i,q,y) \equiv [1-\eta\phi(i,q,y)]y$ denotes the total volume of invasive pest introductions. Both damage from invasive species introductions and inspection costs are assumed increasing and convex in all arguments. We assume that the marginal cost of inspection intensity is increasing in shipment volume, $E_{iy} > 0$ (as is the case, e.g., if i denotes the share of the shipment sampled and inspection intensity equals the volume sampled iy).

Export Shipment Volume and Infestation Rate

The necessary conditions for the exporter's profit maximization problem are:

(3) $$-k\phi_q y - C_q = 0\,,$$

the exporter balances reductions in production cost C_q against expected marginal losses from treatment if invasive pests are discovered $ky\phi_q$; and

(4) $$p - k(\phi + \phi_y y) - \tau - C_y = 0\,,$$

the exporter equates the marginal costs of production C_y and expected marginal losses from treatment if invasive pests are discovered $ky\phi_y$ against the expected net price of the product $p-k\phi-\tau$.

Letting $\Omega \equiv [ky\phi_{qq} + C_{qq}][k\phi_y(2+\psi_y) + C_{yy}] - [k\phi_q(1+\psi_q) + C_{yq}]^2 > 0$, $\psi_q \equiv \phi_{qy}y/\phi_q$, and $\psi_y \equiv \phi_{yy}y/\phi_y$, it is straightforward to show that shipment volume is increasing in the price of the commodity,

$$\frac{\partial y}{\partial p} = \Omega^{-1} C_{qq} > 0$$

and decreasing in the tariff rate,

$$\frac{\partial y}{\partial \tau} = -\Omega^{-1} C_{qq} < 0 .$$

When $\phi_{qy} < 0$, the infestation rate is increasing in the commodity price,

$$\frac{\partial q}{\partial p} = -\Omega^{-1} \left[k\phi_q \left(1 + \psi_q\right) + C_{yq} \right] > 0,$$

and decreasing in the tariff rate,

$$\frac{\partial q}{\partial \tau} = \Omega^{-1} \left[k\phi_q \left(1 + \psi_q\right) + C_{yq} \right] < 0.$$

When $\phi_{qy} > 0$, the signs of the effects of the commodity price and the tariff rate on the infestation rate are indeterminate. Both involve tradeoffs between cost and losses from detected infestations: Higher infestation rates mean lower marginal production costs but higher losses from treatment when invasive pests are detected. When $\phi_{qy} < 0$, the cost effect C_{yq} dominates because the return to higher volume increases relative to the treatment loss effect $k\phi_q(1+\psi_q)$. When $\phi_{qy} < 0$, treatment losses rise with volume, making it possible for the treatment loss effect to dominate.

Import Inspection Intensity

The necessary condition for the importer's cost minimization problem is:

(5) $$E_i - H_z \eta \phi_i = 0 .$$

This condition is sufficient since $Z \equiv E_{ii} y + H_{zz} \phi_i^2 \eta^2 y - H_z \eta \phi_{ii} > 0$. If $\phi_{iq} < 0$, inspection intensity is decreasing in the infestation rate,

$$\frac{\partial i}{\partial q} = Z^{-1} \left(H_z \eta \phi_{iq} - H_{zz} \eta^2 y \phi_q \phi_i \right) < 0 ,$$

since invasive pests are easier to detect in more heavily infested cargoes. The effect of shipment volume on inspection intensity depends on the sign of ϕ_{iy},

$$\frac{\partial i}{\partial y} = Z^{-1}\left(H'\eta\phi_{iy} - H''\eta\phi_i[1-\eta\phi(1-\varepsilon)] - E_{iy}\right),$$

where $\varepsilon = \phi_y y/\phi > 0$. The marginal cost of inspection is higher when shipment volume is higher, creating an incentive to reduce inspection intensity. If $\phi_{iy} < 0$ and ϕ is not highly elastic with respect to y, the marginal productivity of inspection intensity—and thus marginal damage avoided—is also lower in higher volume shipments, creating an unambiguous incentive to reduce inspection intensity. If $\phi_{iy} > 0$, the marginal productivity of inspection intensity and thus marginal damage avoided may be increasing in shipment volume; in this case, the sign of $\partial i/\partial y$ depends on the relative magnitudes of the avoided damage and inspection expenditure effects.

Data

The empirical portion of this project utilizes data collected by APHIS during its screening of commodity imports in combination with data from Foreign Agricultural Trade of the United States (FASOnline).

The conceptual framework discussed above suggests that the prevalence of invasive pests in import shipments will likely be influenced by production conditions and technology, which vary according to the type of commodity and the country or region of origin, and the regulatory regime of the importing country. Data on these items can be found in APHIS records. Characteristics of all propagatable and non-propagatable import cargoes arriving at all US ports (except certain ones on the US-Canada and US-Mexico borders) are recorded on APHIS/PPQ Forms 264 and 280. The APHIS 280/264 data include the date of entry, the port of entry, the name and type of commodity, the shipment's country of origin, and the quantity of the commodity contained in the shipment. The APHIS 280/264 data also include information on the regulatory regime covering the commodity, specifically, whether the commodity was inspected and cleared in the country of origin (e.g., grapes in Chile) or inspected at reduced rates under the National Agricultural Release Program (NARP) or its predecessor, the Border Cargo Release program, which apply to selected fruits and vegetables originating in Mexico and Central America and entering the US from Mexico.

All plant materials entering the US, including packing materials but excluding those entering under pre-clearance or NARP or subject to pre-treatment, are inspected for potential invasive pests. Some shipments entering under pre-clearance or NARP, or pre-treated are inspected to ensure ongoing compliance with the terms of those programs. The APHIS 280/264 data include information on the results of those inspections in the form of the disposition of the shipment, such as whether the cargo was inspected and released for entry; cleared for entry without inspection due to pre-clearance or coverage under NARP; cleared for entry into the US due to pre-treatment; fumigated prior to entry; re-exported or returned due to contamination or presence of an invasive pest; or destroyed due to contamination or presence of an invasive pest.

These surveillance records contain no information on prices or tariff rates, so we use Customs data reported on a monthly basis by commodity and country of origin to estimate them. To merge these data, we aggregated commodities into groups that correspond to categories identified by the Harmonized Tariff Schedule of the United States. We grouped most commodities at the 6-digit HTS code level; that allowed us to get sufficient numbers of observations with actionable pest detections. We use the Customs data to estimate average unit values for each commodity by country and month by dividing the value of imports by the volume of imports. Average tariff rates are similarly estimated by country and month by dividing customs duties paid by the volume of imports.

We use complete APHIS 280/264 records for all individual shipments for the federal fiscal years 2005-2007. Those surveillance records report inspections of 685,962 shipments of fresh fruit and vegetable commodities entering the US during FY 2005-2007. Actionable pests (that is, pests requiring treatment or pests prohibited from entering the US) were detected in 2.6% of those shipments. We were able to match unit values and unit tariff rates with 534,699 of these shipments, about 80% of the total. Actionable pests were found in 3.2% of those shipments.

Model Specification

Our econometric model takes as a dependent variable a discrete indicator of whether invasive pests were detected during inspection of an individual shipment. The theoretical framework discussed above suggests that the probability that actionable pests were detected in a shipment should depend on the import volume, the value of the commodity, the tariff rate, the background pest infestation rate, losses when treatment is made necessary by detection of invasive pests, and potential damage from introductions. We use commodity type, region of origin, and the season in which the commodity was grown to proxy several of these factors. The background pest infestation rate should depend in large measure on the type of commodity, the country of origin, and growing season. Losses when treatment is necessary should also depend in large measure on the type of commodity, country of origin, and growing season. Potential damage from pest introductions should depends on the type of commodity and the growing season.

We aggregated countries of origin into 12 regions of origin because the number of detections was too small to support estimation of coefficients for more disaggregated classifications. We distinguish two growing seasons in each country of origin: summer (May through October in the Northern Hemisphere and November through April in the Southern Hemisphere) and winter (November through April in the Northern Hemisphere and May through October in the Southern Hemisphere). We expect that the pest prevalence in exporting countries and thus infestation rates in import shipments tend to be greater in summer than winter.

Inspection often ceases on discovery of a single actionable pest, which suffices for regulatory action, so that inspection records are most appropriately interpreted as indicating whether at least one invasive pest was detected (McCullough et al. 2006). The considerations discussed above suggest that the probability that at least one actionable pest is detected in shipment j, ϕ_j, conditional on the characteristics of the shipment, should be specified as:

(6) $\phi_j = f(a_0 + \Sigma_k a_{1k}\text{Commodity Type}_{jk} + \Sigma_m a_{2m}\text{Origin}_{jm} + \Sigma_t a_{4t}\text{Season}_{jt} + a_5 p_j + a_6 y_j + a_7 \tau_j)$.

Our theoretical model implies

$$\frac{d\phi_j}{dy_j} = \phi_y + \phi_i \frac{\partial i}{\partial y}, \quad (7)$$

$$\frac{d\phi_j}{dp_j} = \left(\phi_q + \phi_i \frac{\partial i}{\partial q}\right)\frac{\partial q}{\partial p}, \quad (8)$$

(9) $$\frac{d\phi_j}{d\tau_j} = \left(\phi_q + \phi_i \frac{\partial i}{\partial q}\right)\frac{\partial q}{\partial \tau},$$

where the exclusion of indirect effects via changes in shipment volume y_j in equations (8) and (9) arises from the fact that we control for volume in equation (6). Our theoretical analysis indicates that the marginal effects of the commodity price and the tariff rate should be opposite in sign. It makes few definite predictions about the signs of these marginal effects otherwise because the indirect effects of shipment volume, commodity price, and tariff rate on inspection intensity may be opposite in sign to their direct effects.

We estimate equation (6) using a logit specification. Table 1 shows the estimated coefficients of a model containing the full set of independent variables. We used these estimated coefficients to calculate probabilities predicted probabilities that an invasive pest would be detected for all combinations of commodity type, region of origin, and season in our data set, with associated confidence intervals estimated by applying a logit transformation to the upper and lower bounds of 95 percent confidence intervals for the linear predictor $a_0 + a_{1k}\text{Commodity Type}_{jk} + a_{2m}\text{Origin}_{jm} + a_{4t}\text{Season}_{jt} + a_5 p_j + a_6 y_j + a_7 \tau_j$ evaluated at the sample averages of commodity price, shipment volume, and tariff rate. We then calculated the ratio of the predicted probability of detection to the sample average, 3.2%, as a measure of the relative risk of an invasive species introduction for each commodity type/region of origin/season combination. The estimated probabilities of invasive species detection and relative risks of invasive species introductions of the highest and lowest risk commodity/region/season combinations are reported in Tables 2 and 4, respectively.

We also estimated the scale of invasive species introductions by multiplying these estimated probabilities by the average annual number of shipments of each commodity type from each region of origin during each season over our sample period. The estimated numbers of shipments containing invasive species of the highest risk commodity/region/season combinations are reported in Table 3.

Finally, we estimated a separate model that included regions of origin and season along with shipment volume, commodity price, and tariff rate (i.e., omitting commodity type) as a means of examining aggregate risks of invasive species introduction across trading partners. The estimated probabilities of invasive species detection, relative risks of invasive species introductions, and numbers of shipments containing invasive species by region of origin are reported in Table 5.

Empirical Results

The probability that at least one invasive pest is detected in a shipment is increasing in the commodity price and decreasing in shipment volume and the tariff rate: Interceptions of invasive pests are more likely in higher value cargoes, smaller volume shipments, and commodities facing lower tariff rates (Table 2). As our theoretical model predicts, the effects of commodity price and tariff rate are opposite in sign. The positive coefficient of the commodity price and negative coefficient of the tariff rate are consistent with $\phi_{qy} < 0$, as we expect. The coefficients of the commodity price and tariff are consistent with the direct effects of these variables outweighing their indirect effects via changes in inspection intensity. The coefficient of shipment volume indicates the opposite, that inspection intensity is sufficiently lower in high volume shipments to outweigh the positive direct effect of shipment volume on the probability of invasive pest detection.

One possible explanation for the negative effect of shipment volume on inspection intensity is that limits on the numbers of inspectors result in rapidly rising (implicit) marginal inspection costs. Another, non-exclusive explanation is that the number of samples needed to detect invasive pests with any given confidence level (hence inspection intensity) decreases with shipment volume.

Risk of Actionable Pests Detections by Commodity, Region of Origin, and Growing Season

As noted above, we expect commodity type to be correlated with a number of factors that influence the rate of invasive pest introductions, specifically, the background rate of infestation, potential damage from introduced invasives, and treatability of infested cargoes. Table 2 shows the two dozen commodity/region/season combinations with the highest predicted probabilities of actionable pest detections that are significantly greater than the overall average of 3.2% at a 5% significance level.

The list of highest risk imports is dominated by a handful of commodities: Spices, grapes, citrus fruits (oranges, lemons/limes, tangerines/clementines), herbs, and pineapples.

The model estimates that invasive pests will be found in roughly 30-40% of spice shipments from Africa and Southeast Asia, 9-12 times the overall average detection rate. Predicted detection rates in shipments of spices from the European Union, the Middle East, Mexico, and the Caribbean were also quite high—on the order of 13-18% of shipments—but were estimated imprecisely and were thus not significantly different from the overall average at a 5% significance level.

The model estimates probabilities of invasive pest detections on grapes at 3-11 times the overall average. Predicted detection rates on grapes grown in Africa during the summer were exceptionally high at 11 times the overall average; but detection rates on grapes from other regions and growing seasons were all significantly higher than the overall average, with most falling in the range of 3-5 times the overall average. Grapes account for 10 of the 100 riskiest commodity/region/season combinations predicted by our model.

Citrus fruits in general tend to have high risks of invasive species introductions, accounting for 26 of the 100 riskiest commodity/region/season combinations predicted by our model. Lemons and limes tend to have the highest predicted probabilities of invasive pest detections, ranging from 2-9 times the overall average, with the highest risk shipments originating in Africa, the European Union, and Central and South America. Predicted invasive pest detection rates on clementines and tangerines from most regions are also quite high, ranging from 2-5 times the overall average. Predicted detection rates from Africa and the European Union are especially high. Predicted detection rates of invasive pests on clementines and tangerines from some regions—notably the Caribbean—are equal to or somewhat less than the overall average.

Pineapples from Africa, Southeast Asia, and Central America have high predicted probabilities of invasive species detection, on the order of 3-4 times the overall average. But not all pineapples are especially high-risk: The estimated probabilities of invasive species detections on pineapples from Mexico are only slightly higher than the overall average while those from the Caribbean are slightly lower.

The list of commodity/region/season combinations with the largest predicted number of invasive pest introductions is somewhat different (Table 3). Herbs (bay leaves/oregano/etc., basil/mint/etc.), mainly from Mexico, Central and South America, and the Middle East, still figure prominently as high risk commodities while spices do not due to the low number of spice shipments. Pineapples account for a large number of predicted invasive pest introductions, albeit from Central America rather than Africa. Lemons and limes from Mexico are high risk in terms of predicted number of invasive pest introductions while other citrus fruits are not. Squash and other vegetables from Mexico and Central America along with tomatoes and peppers from the European Union have predicted probabilities of invasive pest detections roughly equal to the sample average but account for large numbers of predicted introductions because of the large number of shipments.

At the other end of the spectrum, the commodities with the lowest probabilities of actionable pest detections are largely vegetables—carrots/turnips, potatoes, leeks, chicory/escarole, mushrooms, truffles—along with peanuts and grapefruit, all of which have predicted probabilities of invasive pest detection half the sample average or less (Table 4).

It is notable that avocados (not shown in Table 4) have an extremely low risk of actionable pest intercepts, with predicted probabilities ranging from 0.5-0.7% for avocados from Mexico to 1.1% for summer-grown avocados from Central America. Opening up the US market to avocados from Mexico was highly controversial. California growers in particular argued that doing so would put domestic avocado production at risk from pests contained in imports of Mexican avocados. In response to those fears, imports of Mexican avocados were restricted to shipments to the Northeast during the winter months only for a number of years (Peterson and Orden 2008). Our model indicates that relaxation of those restrictions was entirely justified.

Risk of Invasive Pest Introductions by Region of Origin

Like commodity type, region of origin is of interest because we expect it to be correlated with factors like the background rate of infestation, potential damage from introduced invasives, and treatability of infested cargoes. We estimated relative risk for countries grouped into 12 regions (Table 5).

Africa is the region with by far the highest probabilities of actionable pest detections. The predicted probability of invasive pest detections in cargoes from Africa is 3.5-4.0 times the overall sample average, regardless of growing season. Obvious source of suspicion are high background pest infestation rates coupled with poor sanitation practices. The predicted number of invasive pest introductions is modest, however, because the number of shipments from Africa is relatively low. Our model indicates that any expansion of trade with this region is likely to result in greater frequency of invasive pest introductions.

We looked at Canada and Mexico separately because of their free trade agreement with the US. These two countries are of special interest from a policy perspective because US growers have often cited the risk of pest invasions a reason for continuing the uphold trade barriers with these countries. We find mixed evidence for this contention. The rate of invasive pest detections from Canada is extremely low, less than half the sample average. Our model indicates that Canada accounts for a negligible share of shipments containing invasive pests. The predicted probability of invasive pest detections from Mexico is higher than Canada's, but in the same ballpark as the overall average rate. The predicted number of invasive pest introductions in cargoes from Mexico is large, however, because of the large number of fruit and vegetable shipments: Mexico accounts for 28% of shipments containing invasive pests. Thus, Mexico poses a moderate risk of invasive pest introductions.

The US has free trade agreements with Central America, Chile, and Peru and grants preferential access to imports of many commodities from the Caribbean under the Caribbean Basin Initiative. Fruit and vegetable imports from other South American countries like Argentina and Brazil have been growing as well. Our model indicates that South and Central America pose higher than average risks of invasive pest introductions. Fruit and vegetable imports from South America in the summer account for the largest number of predicted invasive pest introductions, a rate 1.4 times the overall sample average. The share of total annual invasive pest introductions from South America (27%) is almost equal to that from Mexico even though it accounts for 20% of total shipments compared to 31% from Mexico. The predicted probability of invasive pest detections from Central America is similarly higher than the average in both seasons while the number of shipments containing invasive pests is quite large. Central America accounts for 19% of shipments containing invasive pests while accounting for 17% of total fruit and vegetable shipments. These results suggest that the expansion of free trade in the Western Hemisphere is likely to pose challenges for the enforcement of US phytosanitary standards.

We also looked at China separately because China has been the source of some of the most notorious recent invasive pest introductions, like the Asian longhorned beetle (first discovered in the US in 1996) and the emerald ash borer (first discovered in the US in 2002), both thought to have arrived in wood packaging material. We wanted to see if fruit and vegetable imports were similarly problematic. China has also been involved in a number of scandals involving tainted products like milk powder, pet food, and heavy metals in toys, raising some broader issues about sanitation in Chinese imports that make China worth looking at separately. Interestingly, China has a very low incidence of invasive pests in the fruits and vegetables it exports to the US: Less than 0.5% of those cargoes have actionable pest detections. Overall, it appears that the risk of invasive pest introductions from fruit and vegetable imports from China (including actionable pests found in cargo containers outside of the cargo itself) is extremely low.

Conclusion

Expanded world trade carries with it increased risks of invasions of exotic species and thus increased risks of ecological and economic damage. In the face of such risks, expansion of trade depends critically on the ability to detect unintended introductions of organisms in import shipments and determine whether those introductions are safe as is, safe after appropriate treatment, or unsafe even after treatment. This paper investigates factors associated with greater incremental risk of invasive pest introductions both theoretically and empirically.

We develops a conceptual framework based on the production-theoretic notion that invasive pests, like other forms of pollution, can be viewed as an input (or joint output) that serves to lower the cost of producing a commodity. We show that in equilibrium, the prevalence of invasive pests in import shipments depends on production conditions and technology in the exporting country, commodity value and volume, and tariff rates. We use these results to specify an econometric model of factors associated with heightened risk of invasive pest introductions. The parameters of the model are estimated using data from surveillance screening of fruit and vegetable imports into the US during fiscal years 2005-2007. The estimated parameters of the model are used to identify commodities and regions of origin of significantly high and low risk of invasive species introductions.

Consistent with the prediction of our theoretical model, our econometric results indicate that commodity price and the tariff rate have opposite effects on the probability that an invasive pest is detected in a shipment. The risk that an invasive pest is found in a shipment is increasing in the commodity price and decreasing in the tariff rate, consistent with the direct effects of these variables outweighing their indirect effects via changes in inspection intensity. Invasive pests are less likely to be detected in larger shipments, indicating that inspection intensity is sufficiently lower in high volume shipments to outweigh the positive direct effect of shipment volume. This result may be an indication of tightly binding constraints on inspection intensity imposed by limited staffing.

Herbs, lemons and limes, and pineapples consistently rank among the commodities with the highest risk of invasive pest introduction, whether measured in terms of predicted probabilities of invasive pest detections or in terms of the predicted number of shipments containing invasive pests. Squash and other vegetables from Mexico and Central America rank high in terms of the predicted numbers of shipments containing invasive pests. Grapes, oranges, clementines and tangerines, and spices rank high in terms of the predicted probability an invasive pest is detected. Commodities with negligible risks of invasive pest introductions include potatoes, carrots, escarole, leeks, grapefruit, mushrooms, and truffles. Avocados, which have been the focus of intense policy debate, have low risks of invasive pest introductions, as do all fruit and vegetables from China.

The results of our econometric analysis indicate that fears about phytosanitary challenges associated with free trade pacts like the North American and Central America Free Trade Agreements have some basis. Fruit and vegetable imports from Central and South America have relatively high risks of invasive species introductions while imports from Mexico have risks roughly equal to the sample average. (Imports from Canada, in contrast, pose very small risks of invasive pest introductions.) These results indicate that the expansion of free trade within the Western Hemisphere is posing challenges to the enforcement of US phytosanitary standards and that further expansion will likely heighten those challenges.

References

Costello C., M. Springborn, C. McAusland, and A. Solow. 2007. Unintended Biological Invasions: Does Risk Vary by Trading Partner? , *Journal of Environmental Economics and Management* 54, 262-76.

International Plant Protection Convention. 2008. Standards for Phytosanitary Measures: Methodologies for Sampling of Consignments, ISPM No. 31, Rome.

Lichtenberg, E. 2002. Agriculture and the Environment, in Handbook of Agricultural Economics, B. Gardner and G. Rausser, eds., Amsterdam, Elsevier Science, 1249-1313.

Margolis, M., J.F. Shogren, and C. Fischer. 2005. How Trade Policies Affect Endangered Species Control, *Ecological Economics* 52, 305-313.

McAusland, C. and C. Costello. 2004. Avoiding Invasives: Trade-Related Policies for Controlling Unintentional Exotic Species Introductions, *Journal of Environmental Economics and Management* 48, 954-77.

McCullough, D.G., T.T. Work, J.F. Cavey, A.M Liebhold and D. Marshall. 2006. Interceptions of Nonindigenous Plant Pests at US Ports of Entry and Border Crossings over a 17-Year Period, *Biological Invasions* 8, 611-630.

National Research Council. 2002. Predicting Invasions of Nonindigenous Plants and Plant Pests. Washington, DC: National Academy Press.

Office of Technology Assessment. 1993. Harmful Non-Indigenous Species in the United States. OTA-F-565, Washington, DC: US Government Printing Office.

Peterson, E. and D. Orden. 2008. Avocado Pests and Avocado Trade. *American Journal of Agricultural Economics* 90, 321-335.

Venette, R.C., R.D. Moon and W.D. Hutchison. 2002. Strategies and Statistics of Sampling for Rare Individuals, *Annual Review of Entomology* 47, 143-74.

Work, T.T., D.G. McCullough, J.F. Cavey and R. Komsa. 2005. Arrival Rate of Nonindigenous Insect Species into the United States through Foreign Trade, *Biological Invasions,* 7, 323-332.

Table 1. Estimated Coefficients of the Full Logit Model[1]

Variable	Estimated Coefficient	Standard Error
Intercept	-5.0896	6.8594
Shipment Volume (kg)	-0.9657**	0.1172
Commodity Unit Value ($/kg)	0.00337**	0.00123
Unit Tariff ($/kg)	-0.146	0.1283
Region of Origin		
Caribbean	0.3446	5.8456
Central America	1.0078	5.8456
China	-0.8523	5.8479
East Asia	-0.1068	5.8485
European Union - 27	0.8728	5.8456
Mexico	0.5341	5.8456
Middle East	0.6271	5.8456
Oceania	0.916	5.8463
Other Europe	-6.1346	70.1438
South America	0.7962	5.8456
Southeast Asia	1.3864	5.8489
Sub-Saharan Africa	1.9608	5.8466
Season in Region of Origin		
Summer	0.1404	0.00825
Commodity Type (HTS Code)		
Potatoes	-1.6926	3.755
Tomatoes	0.9784	3.5929
Onions	1.2048	3.5931
Garlic	0.424	3.5974
Leeks	-0.5631	3.5952
Cauliflower	-1.0256	3.6597
Brussels Sprouts	-0.7442	3.6264
Lettuce	1.3716	3.5931
Arugula	-0.238	3.5966
Chicory, Escarole	-1.9516	3.6196
Carrots, Turnips	-1.3662	3.6095
Beets, Parsnips, Chard, etc.	0.8227	3.5936
Cucumbers	-0.5427	3.5943
Peas	0.6378	3.5933

[1] The omitted category is apples from Canada in winter.

Beans	0.9473	3.5929
Chickpeas, Lentils	-0.9762	3.6597
Asparagus	0.8671	3.5938
Eggplant	-0.0288	3.5938
Celery	0.9686	3.5961
Mushrooms	-0.198	3.6016
Peppers	0.5696	3.5929
Spinach	1.0312	3.5958
Squash, Other Vegetables	1.0301	3.5927
Cassava, Lily Bulb	0.2926	3.5945
Sweet Potatoes	-0.9384	3.6153
Yams	0.3245	3.5935
Nuts	1.1941	3.598
Coconuts	-0.0418	3.5963
Bananas	0.354	3.593
Dates, Figs	0.6908	3.6383
Pineapple	1.2193	3.5929
Avocados	-0.497	3.5951
Mangos, Guavas	0.9567	3.5931
Oranges	1.9262	3.5948
Clementines, Tangerines	1.4105	3.5956
Grapefruit	-10.8523	147.5
Lemons, Limes	2.1795	3.5929
Citron, Kumquat	-0.9622	3.7264
Grapes	2.3896	3.5935
Watermelons	0.9906	3.5939
Canteloupes, Honeydews	-0.2237	3.5937
Papayas	0.2087	3.5937
Pears	-0.1409	3.5992
Apricots	0.394	3.6054
Cherries	0.2788	3.5946
Peaches	-0.4219	3.5959
Plums	1.1601	3.5945
Strawberries	1.6182	3.5949
Blackberries, Raspberries	0.6934	3.593
Blueberries, Cranberries	0.4926	3.5933
Kiwis	1.8375	3.5973
Durian	0.5131	3.6055
Gooseberries, Other Fruit	0.6869	3.5936
Spices	2.7204	3.776

Ginger	0.9385	3.5949
Turmeric	-0.1332	3.7269
Bay Leaves, Oregano, etc.	1.6412	3.5927
Peanuts	-9.0841	155.5
Ginseng	2.181	3.6878
Basil, Mint, etc.	1.4928	3.5927
Cabbage	1.117	3.5939
Broccoli, Greens	1.0104	3.5931
Truffles	-11.42	72.8659

Table 2. Commodity/Region/Season Combinations with the Highest Probability of Actionable Pest Detections

Commodity	Region	Season	Detection Probability	Confidence Interval		Relative Risk
				Lower Bound	Upper Bound	
Spices	Africa	Winter	0.391	0.059	0.867	12.225
Grapes	Africa	Summer	0.347	0.288	0.411	10.841
Spices	Southeast Asia	Summer	0.294	0.039	0.811	9.186
Lemons, Limes	Africa	Winter	0.272	0.224	0.327	8.509
Oranges	Africa	Summer	0.250	0.192	0.320	7.827
Oranges	Africa	Winter	0.225	0.171	0.290	7.033
Bay Leaves, Oregano, etc.	Africa	Winter	0.179	0.145	0.219	5.602
Basil, Mint, Herbal Teas	Africa	Summer	0.178	0.144	0.218	5.565
Clementines, Tangerines	Africa	Summer	0.166	0.120	0.225	5.198
Spices	Middle East	Summer	0.163	0.019	0.664	5.096
Grapes	European Union	Summer	0.152	0.130	0.176	4.743
Grapes	Central America	Winter	0.151	0.131	0.173	4.722
Clementines, Tangerines	Africa	Winter	0.148	0.106	0.201	4.618
Lemons, Limes	Central America	Summer	0.142	0.131	0.154	4.449
Grapes	South America	Summer	0.142	0.125	0.162	4.443
Pineapples	Africa	Summer	0.141	0.115	0.174	4.422
Nuts	Africa	Summer	0.138	0.092	0.203	4.327
Grapes	European Union	Winter	0.135	0.115	0.157	4.206
Lemons, Limes	Oceania	Summer	0.132	0.108	0.159	4.110
Lemons, Limes	European Union	Summer	0.127	0.115	0.140	3.958
Lemons, Limes	Central America	Winter	0.126	0.116	0.137	3.940
Grapes	South America	Winter	0.126	0.110	0.144	3.935
Pineapples	Africa	Winter	0.125	0.101	0.154	3.915
Onions	Africa	Winter	0.124	0.097	0.156	3.866

Table 3. Commodity/Region/Season Combinations with the Largest Number of Invasive Pest Introductions

Commodity	Region	Season	Average Number of Shipments per Year	Predicted Number of Shipments with Invasive Pests Detected per Year
Bay Leaves, Oregano, etc.	South America	Summer	4144	301
Bay Leaves, Oregano, etc.	South America	Winter	4064	259
Squash, Other Vegetables	Mexico	Summer	6554	208
Squash, Other Vegetables	Mexico	Winter	7096	196
Squash, Other Vegetables	Central America	Winter	4283	187
Squash, Other Vegetables	Central America	Summer	3545	177
Basil, Mint, etc.	Mexico	Winter	3445	149
Basil, Mint, etc.	South America	Summer	2224	141
Basil, Mint, etc.	Mexico	Summer	2739	135
Basil, Mint, etc.	South America	Winter	2239	124
Bay Leaves, Oregano, etc.	Middle East	Summer	1905	118
Bay Leaves, Oregano, etc.	Middle East	Winter	2060	112
Pineapples	Central America	Summer	1790	107
Tomatoes	European Union	Summer	2137	89
Peppers	European Union	Summer	3043	86
Basil, Mint, etc.	Middle East	Summer	1541	83
Pineapples	Central America	Winter	1496	78

Table 4. Commodity/Region/Season Combinations with the Lowest Probability of Actionable Pest Detections

Commodity	Region	Season	Detection Probability	Confidence Interval		Relative Risk
				Lower Bound	Upper Bound	
Chicory, Escarole	South America	Winter	0.002	0.001	0.004	0.059
Carrots, Turnips	Canada	Summer	0.002	0.000	0.994	0.055
Leeks	China	Summer	0.002	0.001	0.003	0.052
Chicory, Escarole	Mexico	Summer	0.002	0.001	0.004	0.052
Carrots, Turnips	East Asia	Summer	0.002	0.001	0.003	0.049
Carrots, Turnips	Canada	Winter	0.002	0.000	0.993	0.047
Leeks	China	Winter	0.001	0.001	0.002	0.045
Chicory, Escarole	Mexico	Winter	0.001	0.001	0.003	0.045
Carrots, Turnips	East Asia	Winter	0.001	0.001	0.003	0.043
Potatoes	Canada	Summer	0.001	0.000	0.993	0.039
Chicory, Escarole	Caribbean	Winter	0.001	0.000	0.003	0.037
Potatoes	Canada	Winter	0.001	0.000	0.992	0.034
Carrots, Turnips	China	Summer	0.001	0.000	0.002	0.023
Bay Leaves, Thyme, etc.	Other Europe	Summer	0.000	0.000	1.000	0.002
Clementines, Tangerines	Other Europe	Winter	0.000	0.000	1.000	0.002
Tomatoes	Other Europe	Summer	0.000	0.000	1.000	0.001
Mushrooms	Other Europe	Summer	0.000	0.000	1.000	0.000
Mushrooms	Other Europe	Winter	0.000	0.000	1.000	0.000
Peanuts	All Regions	Summer	0.000	0.000	1.000	0.000
Peanuts	All Regions	Winter	0.000	0.000	1.000	0.000
Grapefruit	All Regions	Winter	0.000	0.000	1.000	0.000
Grapefruit	All Regions	Summer	0.000	0.000	1.000	0.000
Truffles	All Regions	Summer	0.000	0.000	1.000	0.000
Truffles	All Regions	Winter	0.000	0.000	1.000	0.000

Table 5. Risk of Invasive Pest Introductions by Region of Origin and Growing Season

Region	Season	Detection Probability	Confidence Interval		Average Number of Shipments per Year	Predicted Number of Shipments with Invasive Pests Detected per Year	Relative Risk
			Lower Bound	Upper Bound			
Africa	Summer	0.126	0.103	0.152	522	66	4.0
Africa	Winter	0.111	0.090	0.135	355	39	3.5
Oceania	Summer	0.044	0.038	0.052	2172	96	1.4
South America	Summer	0.043	0.042	0.045	73935	3191	1.4
Southeast Asia	Summer	0.042	0.031	0.055	667	28	1.3
Middle East	Summer	0.042	0.040	0.044	19394	808	1.3
Central America	Summer	0.040	0.038	0.041	39205	1549	1.3
Oceania	Winter	0.039	0.033	0.045	2103	81	1.2
South America	Winter	0.038	0.036	0.039	50136	1885	1.2
Southeast Asia	Winter	0.036	0.027	0.048	574	21	1.2
Middle East	Winter	0.036	0.035	0.038	24805	900	1.2
Central America	Winter	0.034	0.033	0.036	57762	1987	1.1
Mexico	Summer	0.032	0.031	0.033	75209	2384	1.0
European Union	Summer	0.031	0.029	0.033	25448	782	1.0
Mexico	Winter	0.028	0.027	0.028	101458	2797	0.9
European Union	Winter	0.027	0.025	0.028	19070	510	0.8
Caribbean	Summer	0.018	0.017	0.019	33466	611	0.6
Caribbean	Winter	0.016	0.015	0.017	32520	515	0.5
East Asia	Summer	0.012	0.008	0.017	1636	19	0.4
Canada	Summer	0.011	0.000	0.813	2568	29	0.4
East Asia	Winter	0.010	0.007	0.015	2102	22	0.3
Canada	Winter	0.010	0.000	0.790	2028	20	0.3
China	Summer	0.005	0.004	0.007	3758	19	0.2

China	Winter	0.004	0.003	0.006	4303	19	0.1
Other Europe	Summer	0.000	0.000	1.000	168	0	0.0
Other Europe	Winter	0.000	0.000	1.000	236	0	0.0