Effect of a Differentially Applied Environmental Regulation on Agricultural Trade Patterns and Production Location: The Case of Methyl Bromide

Lori Lynch, Scott Malcolm, and David Zilberman

It has been hypothesized that differentially applied environmental regulations create pollution havens, as firms will choose to invest in countries with lax environmental standards. Using a theoretical model of pest control adoption and an empirical spatial equilibrium model, we examine one such environmental regulation, a U.S. ban on methyl bromide, to determine if an agricultural pollution haven will be created in Mexico. Alterations in agricultural production location, trade patterns, and methyl bromide use are determined. We find that, under the assumptions held, Mexico will not dramatically increase its use of methyl bromide following the ban. Sensitivity analysis to this result is conducted.

Key Words: trade, environmental regulations, methyl bromide, production location, spatial equilibrium model, pesticide adoption

The ongoing debate surrounding most multilateral trade agreements revolves around the potential for conflict between environmental protection and trade liberalization. Environmentalists see trade liberalization and trade agreements as leading to less stringent environmental standards and more difficulty in achieving new environmental regulations, as domestic producers will demand a level playing field. Proponents of trade liberalization, on the other hand, claim that policies to protect the environment are disguised trade barriers.

In recent articles on trade and the environment, researchers have focused on how trade agreements and trade mechanisms affect the environment by either increasing production, shifting production sites, or eliminating production, with many researchers estimating environmental Kuznets curves (see Dean 1992, Nordstrom and Vaughan 1999, and Copeland and Taylor 2003 for surveys of this literature). In addition, attention has been given to how trade instruments, such as a ban on exports or imports, can be used to achieve a reduction in pollution. Other papers have examined how environmental regulations affect trade patterns and firm locations (see Dean 1992, Nordstrom and Vaughan 1999, Copeland and Taylor 2003). Several authors have investigated whether trade liberalization is creating pollution havens or a "race to the bottom," where countries lower (or do not raise) their environmental regulations to attract foreign direct investment. Environmental regulations may or may not achieve their intended goal, or may do so in a

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way that distorts resource allocation and imposes large welfare losses (Sullivan 1994).

Our research examines how differentially applied environmental regulations can impact agricultural trade patterns and production location. We develop a model to predict and test whether an agricultural pollution haven effect is found with respect to Mexico following the U.S.'s phaseout of methyl bromide. To do this, we incorporate cost, yield, and pest pressure differences due to geographic and climatic differences by region or country into the empirical study. Dean, Lovely, and Wang (2005) find that production differences due to different levels of access to technology may affect the impact of the environmental regulations—for example, identical regulations may impact less technologically advanced countries' investment more. Thus, heterogeneity beyond regulatory differences can have important implications in the degree to which the stringency of environmental regulations determines production location. In our model, the heterogeneity derives not from differential access to technology but to climatic differences and varying levels of pest pressure that result in varying demands for pest control. The pest control in question, methyl bromide, depletes the ozone layer—i.e., it is a global rather than local pollutant. We can examine whether, if regulations are imposed in one country to restrict the use of an environmentally damaging pest control, affected growers relocate production to another country or region with less strict regulations or with less pest pressure. Changes in technology use and cropping patterns as a result of a unilateral (i.e., single region's) change in an environmental regulation are examined.

While previous studies have examined the impact of a unilateral ban on methyl bromide (USDA 1993, Ferguson and Padula 1994, Sunding et al. 1993, Yarkin et al. 1994, Deepak, Spreen, and VanSickle 1994, Deepak, Spreen, and VanSickle 1996, Lynch 1996, Carpenter, Gianessi, and Lynch 2000), only Lynch (1996) included the possibility that Mexican growers would increase their use of methyl bromide following the ban's implementation and thereby dilute the environmental objective of the policy. This research extends Lynch's work, developing a theoretical model and incorporating more crops and regions into the empirical analysis.

Three possible outcomes of unilateral environmental regulation exist: (i) production shifts to the foreign country without regulation, increasing global use of methyl bromide use; domestic prices increase; foreign production increases; and domestic production decreases; (ii) production shifts to the foreign country, but the foreign country does not adopt methyl bromide, so global use decreases, domestic prices increase, foreign production increases, and domestic production decreases; and (iii) production does not shift to a foreign country, domestic production decreases, and domestic prices increase. Under scenario (i), global use of the chemical increases and large costs are imposed on domestic producers. Under scenarios (ii) and (iii), global use decreases, but the costs to domestic producers will vary, with lower domestic costs under scenario (iii).

Background

Methyl bromide emissions contribute to ozone loss. The ozone layer protects the earth from the damaging effects of ultraviolet (UV) radiation from the sun. UV is responsible for "normal" skin changes, such as sunburn and tanning, and "abnormal" changes such as skin cancer. It is estimated that for every one percent decrease in stratospheric ozone, the incidence of malignant melanoma skin cancer will increase 0.6 percent, non-melanoma skin cancer 3 percent, and cataracts 1.2 percent (Urbach 1990). Fifteen to 35 percent of the total amount of methyl bromide entering the atmosphere is from human agricultural activities. One of the major human uses is soil fumigation for horticulture crops. The percentage of total applied methyl bromide that emits into the atmosphere from soil treatments ranges from 30–85 percent.

The U.S. Clean Air Act requires the phaseout of any substance with an ozone depletion level (ODP) of 0.2 or higher. When the Montreal Protocol parties listed methyl bromide with an ODP of 0.7 (revised to 0.6) in 1992, the U.S. Environmental Protection Agency (EPA) instituted a unilateral ban on the production and importation of methyl bromide after January 1, 2001. However, none of the parties to the Montreal Protocol had agreed, as of 1992, to a phaseout schedule. For a 5-year period, no regulation on use in Mexico existed.

The parties to the Montreal Protocol adopted a phaseout schedule in 1997. The U.S. Congress amended the Clean Air Act to harmonize the U.S. schedule with the Protocol's, requiring a 100 percent reduction in production and importation by 2005. The Protocol allows developing countries that recognize the Montreal Protocol, such as Mexico, to continue using methyl bromide until 2015. Production and importation of methyl bromide by these countries is restricted to decreasing percentages of its 1995–1998 levels. Mexico's baseline level has been set at 1,885 metric tons of methyl bromide. Mexico used 1,878 metric tons of methyl bromide in 1997. This includes uses for all purposes—not specifically for horticultural crops, as we investigate here. As of 2004, the United States had phased out 70 percent of its methyl bromide use. In the spring of 2004, the United States requested and received critical use exemptions for 2005 for 7,659 metric tons, delaying the complete phaseout by at least one year.

The North American Free Trade Agreement was passed in 1993, decreasing tariffs on fruit and vegetable imports from Mexico. This change in comparative advantage was found to impact California and Florida horticultural producers (Cook et al. 1991). The subsequent decision to phase out methyl bromide was found to most directly impact California and Florida (Ferguson and Padula 1994). These two states, California and Florida, used 68 percent of the U.S. consumption of methyl bromide in 1997, at 6,576 metric tons and 5,125 metric tons, respectively. In that year, the United States as a whole used 17,213.7 metric tons, with the major application crops being small fruits and vegetables (69 percent), orchards and vineyards (15 percent), and nurseries (15 percent) (EPA 2002). Forty-seven percent of California's total usage was applied on strawberries; in Florida, the number was 54 percent for tomatoes, 29 percent for peppers, and 10 percent for strawberries. Eggplant, cucumber, and squash growers also utilize methyl bromide in some production systems in Florida. Mexico is a major competitor in these crops but has not utilized methyl bromide widely except on strawberries in Baja California. Currently, as mentioned above, Mexico is limited to 1,885 metric tons of methyl bromide, but does not have to phase it out until 2015.

To investigate the impact of the Montreal Protocol's phaseout schedule on overall methyl bromide use, we develop a theory of pest control adoption and the resulting supply curve for a crop. Using this theory, we develop an empirical model that analyzes the major methyl bromide users and regions to determine whether methyl bromide use will decrease or increase and what the resulting production pattern will be.

Theoretical Model

The case of methyl bromide illustrates the need for models that address heterogeneous regions as well as differences in environmental regulations between countries when exploring the question of a pollution haven. Because of heterogeneity, growers in certain regions may find it profitable to produce different crops and/or use different technologies. For example, heterogeneous regions produce agricultural crops with different yield loss levels resulting from weeds, diseases, and insects that can be based on soil type, weather patterns, and agricultural practices. Soil can contain many types of pathogens that either consume a crop or compete with it for resources. Climatic conditions also impact a pest pathogen's survival and limit the types of controls that are possible. In more temperate and tropical areas, for example, pathogens can survive over the winter months, and few natural conditions exist to control their populations. We incorporate these heterogeneous factors into the model in two ways: a land quality variable defined as the maximum potential yield under ideal conditions, and a pest pressure variable defined as the percent decrease in potential yield due to local pathogens such as insects, weeds, fungi, and nematodes. The model can be generalized to distinguish different levels of pest damage and the resulting costs or benefits of pest control.

Rational producers with different quality land or pest pressures will use different technologies to produce the same crop. The interaction between crop yield and pathogens is important in determining where to plant different crops and in the impact of regulations affecting pest control strategies. In many locations, disease and weed problems are such that without effective control technologies, crop production would not be profitable.

The effectiveness of the control technology can be measured by its ability to prevent crop damage as a function of pest pressure. In many areas, growers choose to use little or no control due to its high cost, with the result that yield decreases. In other regions, they adopt very intensive control measures at high costs and lose relatively little yield due to pest pressure. These control techniques combat the disease problems, increasing land's realized yield.

The theoretical model contains two parts. One has a representative farmer who chooses whether or not to use the pest control technology (we then use this farmer to represent a region in the empirical model). We find that the adoption of the pest control technology will change with increases in output price, pest pressure, and land quality. Using this model, the switching point for adoption can be determined based on land quality and pest pressure. Given the behavior of the individual growers, in the second part, we can generate an industry supply curve. Because the land is heterogeneous in both potential yield and pest pressure, we find varying levels of adoption of the pest control technology.

Let us denote the quality of a given parcel of agricultural land by α, assuming the absence of any pathogens. This land quality α can assume low values for land with little capacity to produce a crop (steep slopes, little or no topsoil, and no water-holding capacity) or land in hostile environments. The highest land quality, α^M, has the maximum yield due to the best soils. The pest pressure, D, is assumed to be exogenous to the land quality and can vary by farm and location. Each acre is defined by an (α, D) combination. Each farmer is assumed to have parcels with homogeneous land quality, although land quality varies across farmers.

Farmers can try to control the pathogens using technology m=1. They can also choose not to control the pathogens, technology m=0. For simplicity, we assume that only one technology can be used to control pests. The effectiveness of technology m is determined by its ability to decrease crop loss on a particular parcel. For example, if no disease pressure exists, the realized yield per acre will equal the potential yield, $y(\alpha)$; if disease pressure exists, the realized yield will be $y(\alpha)(1-k_m(D,x))$, where $y(\alpha)k_m(D,x)$ is the quantity of yield destroyed by the pathogen's presence under technology m. The variable level of control is x. As disease pressure increases, $k_m(D,x)$ becomes larger. As chemical use increases, $k_m(D,x)$ becomes smaller. We assume that the proportion of crop lost is increasing at a decreasing rate (yield per acre is a decreasing function of disease $\partial^2 k / \partial D^2 < 0$) and that the proportion of crop lost is decreasing with control at an increasing rate $\partial^2 k / \partial x^2 > 0$. The cost per unit for the chemical is w, and the quantity used of the chemical is $x(\alpha, D)$ for land quality α and pest pressure D. Control costs per acre can be denoted by $wx(\alpha, D)$.

For simplicity, we look at the theoretical model for one representative farmer growing one crop sold in one market assuming exogenous prices. Therefore, the only decision is whether to adopt the control technology or not. The empirical model will extend this approach to include more than one crop, region, and market. First, each farmer solves equation (1) to choose the optimal level of $x(\alpha, D)$ given his or her land quality and disease pressure. Output price is denoted by P, pc is the per acre cost of using other inputs at their optimal level,[1] hc is the harvest cost per unit y, and tc is the transportation cost per unit y. Output is a function of land quality and pest pressure and is assumed to have constant returns to scale properties using pest control as the input:

$$
\begin{aligned}
(1) \qquad Max_x \Pi &= Py(\alpha)(1-k_m(D,x)) \\
&- [pc + wx(\alpha, D)] \\
&- hcy(\alpha)(1-k_m(D,x)) \\
&- tcy(\alpha)(1-k_m(D,x)).
\end{aligned}
$$

The first-order condition is

$$-Py\frac{\partial k}{\partial x} + hcy\frac{\partial k}{\partial x} + tcy\frac{\partial k}{\partial x} = w,$$

and the second-order condition (SOC) is

$$-Py\frac{\partial^2 k}{\partial x^2} + hcy\frac{\partial^2 k}{\partial x^2} + tcy\frac{\partial^2 k}{\partial x^2} < 0 .$$

All functions in the optimization problem are assumed to be twice continuously differentiable on their entire domains, and the decision variable

[1] We are implicitly assuming that chemical use and other inputs have no interaction with this formulation. In the empirical model, this is somewhat relaxed given the alternative technologies examined.

is subject to a nonnegativity constraint. The first-order condition indicates that each farmer will use x up to the point where the marginal contribution to the value of the "saved" production minus the additional cost to harvest and transport the "saved" production equals the marginal variable cost of the control technology. If the control technology saves more production—i.e., if $\partial k/\partial x$ is large—then a farmer is more likely to use the control technology given w, assuming of course that $P \geq hc + tc$.

Second, each grower will compare the profits earned using pest control at this optimal level $x^*(\varphi)$ to not using any control as depicted in equation (2). The vector φ describes the set of exogenous parameters $(P, w, \alpha, D, pc, hc, tc)$. Growers will use the control technology if

$$\text{(2)}\quad \begin{aligned} x > 0 \text{ if } & (-Py + hcy + tcy) \\ & [k_1(D, x^*(\varphi)) - k_0(D,0)] > wx^*(\varphi) \\ x = 0 \text{ if } & (-Py + hcy + tcy) \\ & [k_1(D, x^*(\varphi)) - k_0(D,0)] \leq wx^*(\varphi). \end{aligned}$$

If the resulting increase in the net revenue from the disease control is greater than the cost of the control, the grower will employ the control. If either the increased yield or the market prices are not sufficiently high, the grower might find that the increased net revenue does not cover the cost of the control technique. Some P, hc, and tc exists such that $(-Py + hcy + tcy)(k_1 - k_0) > wx^*(\phi)$, and the disease control technology will be used in this case. As the value of the crop increases, so does the value of controlling the pest damage. We find the standard results, i.e., that the optimal amount of control will increase with increases in output price and land quality, and decrease with an increase in the variable costs of the chemical. Interestingly, the impact of an increase in disease pressure is indeterminate:

$$\frac{\partial x}{\partial D} = \frac{[Py(\alpha) - hcy(\alpha) - tcy(\alpha)]\dfrac{\partial^2 k(D, x^*)}{\partial x \partial D}}{\text{SOC}}.$$

We know that as pest control use increases, the percent lost will decrease, so the question here is the cross partial. What happens to this relationship as the disease pressure increases? If we can assume that as disease pressure increases, we have that $\partial^2 k(D, x^*)/\partial x \partial D < 0$, then the model would suggest that as disease pressure increases, the amount of pest control would increase.

We can define $\alpha^*(\varphi)$ as the switching quality of land based on output and disease pressure per acre where the profits earned under each technology are equal or $\Pi_1(\varphi) = \Pi_0(\varphi)$. All acreage above this marginal quality and pest pressure will employ the control technology. The lowest yielding land that will enter into production is denoted by α^s. The minimum quality land put into production is defined by $\Pi_0 \geq 0$. For any land quality lower than $\alpha^s(\varphi)$, $\Pi_0(\varphi) < 0$, and this land will remain out of production. The highest yielding land is α^M.

Figure 1 depicts how profits are compared under different land qualities for a given disease pressure to determine if using the control technology is optimal. Farmers with land quality below $\alpha^s{}_0$ will not put their land in production because profit is negative when no control technology is used and quality below $\alpha^s{}_1$ has negative profits when the control technology is used. Farmers with land quality between $\alpha^s{}_0$ and $\alpha^*(\varphi)$ will choose not to use the control technology. Farmers with land quality above $\alpha^*(\varphi)$ will employ the control technology.

Industry Supply

To bridge the theoretical and empirical models, we shift from an individual farmer adopting pest control to a set of representative regions. Within each region, land is assumed to be homogeneous in pest pressure and land quality. Using α as the measure of land quality and D as pest pressure, we can define the joint distribution of acres with quality α and pest pressure D as $g(\alpha, D)$. We assume that $g(\alpha, D)$ is continuous. Because the land is heterogeneous in both potential output and disease pressure, we find varying levels of adoption of disease control technologies, as depicted in equation (2). This leads to the industry supply

$$\text{(3)}\; Y(\varphi) = \int_0^{\bar{D}} \int_{\alpha^s}^{\alpha^*(\varphi)} yg(\alpha, D)(1 - k_0(D,0))\, d\alpha\, dD + \int_0^{\bar{D}} \int_{\alpha^*(\varphi)}^{\alpha^M} yg(\alpha, D)(1 - k_1(D, x^*(\varphi)))\, d\alpha\, dD$$

as the sum of the per acre yield multiplied by aggregate acreage planted without using the control

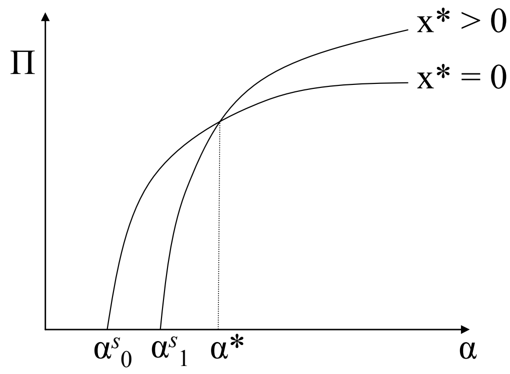

Figure 1. Comparing Profit Levels with Varying Land Qualities: Producers Adopt Control Technology (*x* > 0) with Land Qualities Greater Than α*

technology, and of the per acre yield multiplied by aggregate acreage planted using the technology.

As price increases, the overall industry supply will increase in two ways. More regions will begin to use the control technology, increasing yield on these acres. In addition, lower quality land will come into production. The change in the number of acres in production not using the technology depends on the magnitude of the intensive versus extensive margin (Figure 2). The solid curves in Figure 2 describe a possible technology choice profile for pest pressure/land quality combinations. The curve DE indicates that there is a minimum land quality (α^s) below which production is not profitable. It represents the locus of values of α that defines the extensive margin. The upward slope of the line shows that as land quality rises, the pest pressure threshold for which production becomes profitable increases. Curve EF indicates that for a given land quality, if pest pressure is high enough, it pays to adopt the control technology. This curve represents the locus of values of α* that defines the intensive margin. The downward slope of the curve shows that as land quality increases, the pest pressure threshold for which using the control technology is more profitable than not using it decreases, i.e., as the potential yield increases, the same percentage of loss is a greater number, and thus it becomes beneficial to use the control technology. If price rises, the curves shift to the left, as shown by the dashed lines. Marginal land comes into production (area ABED), and the control technology becomes profitable for more land (area EFGC). The overall increase in control technology use is area BCFE. The intensive margin includes those acres that switch from no control to using the control technology. The extensive margin includes those acres that come into production. To determine if the extensive margin is greater than the intensive margin, one would compare the area ABED to BCFE.

Figure 3 depicts the situation where U.S. producers move from being able to use the yield-enhancing control technology to being banned from using the technology. The solid curve depicts the pre-ban extensive (curve AB) and intensive (curve BC) margins. Regions with certain land quality and pest pressure will continue to produce the crop even without the technology. These regions lie in the area to the right of the dashed line (EFD). Land will come out of production as it becomes unprofitable (area ABDE) or in a trading situation where regions have shifted production to another country or region.

As the cost of the control technology increases, fewer regions will adopt the control technology, which should increase the non-use acreage. As crop yield decreases overall, the market price of the crop may increase, which should result in some previously unprofitable land coming into production. Since the control is in effect increasing the realized yield closer to the potential yield, a decrease in its use will result in more acres needed in production to achieve the same industry supply. We cannot determine whether, as pest pressure increases, more or fewer acres will be using the technology.

If the control technology has negative externalities, society will want to restrict its use. If the consequences of doing so fall most heavily on a certain country, or if the consumers in one area are willing to pay higher prices for the farm product in order to prevent the externalities, a regulation may be imposed that impacts only part of the land under cultivation. The potential yield of acres previously using the control will decrease (intensive margin), and some of this acreage may become unprofitable and stop production (extensive margin). We may see non-regulated regions that had never adopted the technology before begin to use it if decreased supply increases the market price of the farm product sufficiently.

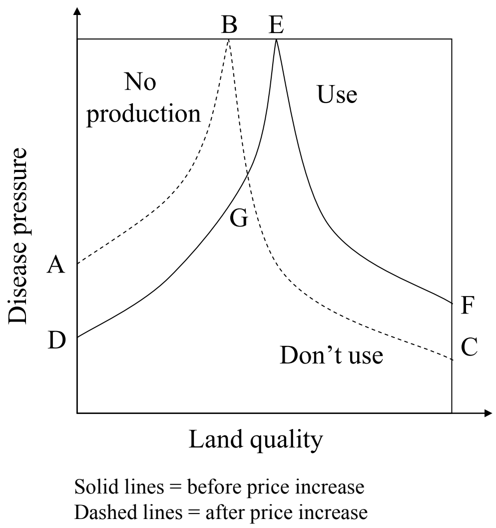

Figure 2. Intensive (EF) and Extensive (DE) Margins for Pest Control Use for Varying Levels of Land Quality and Disease Pressure Before and After Crop Price Increase

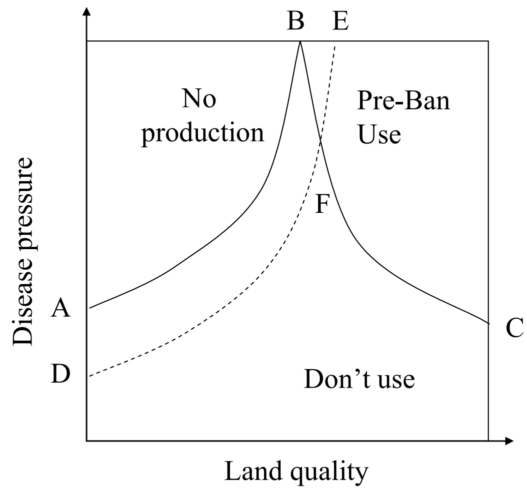

Figure 3. U.S. Production Following Ban on Pest Control Use

Notes: To right of curve EFD, growers will continue to produce without the technology. Land depicted as area ABED will come out of production.

If domestic regions do not face competition from foreign regions, this regulation enforces restricted production similar to a monopoly or monopolistic market structure. Because less product is on the market, the price is higher, and those regions not plagued by pest pressure will benefit from the regulation. In addition, some affected regions may have higher profits by not purchasing the control technology, thus having lower costs and receiving a higher market price if the percent increase in price is greater than the percent decrease in quantity.

However, if foreign regions respond to the new regulation and the higher prices, their increased production may drive domestic regions out of production. This increased foreign production can come from (i) land switching from non-use to use of the control technology, and (ii) new land coming into production. Depending on the magnitude of the price change and the level of previous use of control technology in the foreign country, the overall effect may be a net increase in the level of use of the control technology.

If the negative consequences from the control technology are local, the domestic country has shifted the environmental problem to another country, in essence creating a pollution haven. If the environmental problem is global in nature, such as with methyl bromide, the domestic country may not achieve its environmental objective, while at the same time imposing losses on its producers. We are interested in seeing how differences in cost and yield for crops using methyl bromide will affect trade on a region-by-region basis in the face of differing environmental regulations.

Empirical Model

To determine which of the scenarios outlined above will occur, we examine the impact of a unilateral ban of methyl bromide on the horticultural crops that use methyl bromide extensively and that compete with Mexican producers.[2] To this end, the annual horticultural market including those regions where methyl bromide is used (California, Florida, South Carolina, and North Carolina), as well as their direct competitors (Mexico, Texas, and Georgia), is modeled as a spatial partial equilibrium problem. The model follows the early work of Takayama and Judge

[2] A unilateral ban was in place until 1997. Currently, Mexico also faces some restrictions on methyl bromide use under the Montreal Protocol, which we address when discussing the results.

(1971) as well as similar models that have analyzed the methyl bromide problem (Deepak, Spreen, and VanSickle 1996; Carpenter, Gianessi, and Lynch 2000). This model is extended to include a technology or pest control adoption decision as outlined above.

The empirical model replaces the representative farmer with a representative region, denoted j. Within each region, all land is assumed to be of similar quality and to face similar pest pressure; all farmers within a region are assumed to follow common production patterns. However, crops, costs, yields, and pest pressure vary by region due to geographic, climatic, and other differences. Each region selects whether or not to adopt methyl bromide into its production practices. The sum over all regions' production comprises the total supply of a particular crop.

Because methyl bromide is used on several crops within these regions, the model is further extended to consider six crops, denoted i. Each crop may be grown using one or more production systems, with index h designating the production systems. Each crop and region has a specific set of production practices that are commonly used. For example, cucumbers are grown using one of five production systems: as a single crop, spring planting, fall planting, double-cropped following peppers, or double-cropped following tomatoes. Production systems are limited to those currently used in each region. Since yields are not known for crops in regions where they are not grown, regions are not allowed to shift production into crops not currently grown. Each region will choose the acreage L_{ijhm} of each crop it will plant using technology m, where m = 1 denotes using methyl bromide and m = 0 represents non-use of methyl bromide.

The theoretical model is also extended here to include the demand side of the market. Given that the regions included represent a large percentage of the crop production for the United States, we do not assume exogenous prices but instead permit the price to adjust as supply changes. Each region faces a market price in four representative markets, denoted k. In addition, because prices and yields vary over the year, we extend the theoretical model to permit differences for each of the twelve months, denoted t.

The empirical model maximizes social welfare (SW) as follows:

$$\text{(7a)}\quad Max\ SW = \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{t=1}^{T}(a_{ikt}Q_{ikt} - 1/2\, b_{ikt}Q^2_{ikt}) - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=0}^{1}(pc_{ijhm} + wx_{ijhm})L_{ijhm} - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} hc_{ij}Y_{ijt} - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} tc_{ijk}V_{ijkt}\ ,$$

s.t.

$$\text{(7b)}\quad Y_{ijt} \le \sum_{h=1}^{H}\sum_{m=0}^{1}(1 - k(D, x_{ijhm}))\, y_{ijhtm}L_{ijhm},$$

$$\text{(7c)}\quad Y_{ijt} \ge \sum_{k=1}^{K} V_{ijkt},$$

$$\text{(7d)}\quad Q_{ikt} \le \sum_{j=1}^{J} V_{ijkt}$$

$$Y_{ijt}, V_{ijkt}, Q_{ikt}, x_{ijhm}, L_{ijhm} \ge 0.$$

We compute the equilibrium levels of supply for each crop in each region in each month, Y_{ijt}, the quantity shipped of each crop from each region to each market in each month, V_{ijkt}, the quantity consumed in each market of each crop in each month, Q_{ikt}, as well as the number of acres in each crop in each region in each production system in each pest control technology, L_{ijhm}. The objective is to maximize social welfare (7a), subject to regional production limited to planted acres multiplied by realized yield (constraint 7b), shipment quantity limited to quantity produced (constraint 7c), and quantity consumed limited to quantity shipped (constraint 7d).

The pre-harvest cost per acre of crop i in region j for production system h in pest control technology m is pc_{ijhm}. The cost of methyl bromide per unit is w. The amount used per acre is $x_{ijhm.}$ Harvest and post-harvest costs, which include harvesting, packing, hauling, grading, cooling, tariffs, etc., is hc_{ij}, the per ton cost per crop per region. These costs do not vary by month. Thus the total harvest and post-harvest costs are represented by hc_{ij}* Y_{ijt} for crop i in region j. The transportation cost per ton from region j to demand market k is tc_{ijk}. V_{ijkt} is the total shipments of crop i, from region j to market k in month t. The total cost of transport per month for crop i from region j to market k in month t is represented by tc_{ijk}*V_{ijkt}.

All producers in a particular region are assumed to use the same production and pest control technology and to therefore have the same yields and same costs, but it is assumed that across regions there is variation. Parameter y_{ijhtm} is the per acre yield in crop i in month t in region j for production system h for pest control technology m. Methyl bromide is a yield-enhancing technology; the yield without methyl bromide is some fraction of the potential yield. Yields per acre using methyl bromide and using the alternative technologies are assumed to be non-stochastic. While per acre yields for fruit and vegetables vary from year to year, some of the technologies included are not currently being used in these regions, and thus data on yields over time are not available.

In this formulation, there is some region j that has land quality α_s such that it will not grow crop i at all; another region j with land quality between α_s and α^* that will grow crop i but without using the methyl bromide technology, $m = 0$; another region will have land quality greater than α^*, will grow crop i, and will use methyl bromide technology, $m = 1$. The unobserved values α are not known *a priori*. The model will choose which regions increase, decrease, or stop production for each crop according to relative yield and cost differences between regions.

The inverse demand curve or the marginal benefits curve is represented as $P_{ikt} = a_{ikt} - b_{ikt} Q_{ikt.}$ The demand curve's intercept is a_{ikt} and its slope is b_{ikt}.[3] The slope of the demand function is assumed to be constant over all quantities, and each region's production is assumed to be a perfect substitute for any other region's. The model assumes that the price of each commodity is a function of its own quantity alone—that is, Q_{ikt} is the total quantity demanded as a function of P_{ikt}, the per unit price for the ith crop in the kth market in month t—and that the price is not affected by other crop prices or quantities that may be sold in that market in that month. If this simplification were not assumed, the integrability problem addressed by McCarl and Spreen (1980) and Peters and Spreen (1989) would become an issue.

[3] The true marginal benefits curve would be the Hicksian demand curve rather than the Marshallian demand curve. However, Willig (1976) found that evaluating consumer surplus with the Marshallian demand curve generated only a small approximation error.

Data[4]

The analysis of the annual horticultural market model includes six crops: tomatoes, strawberries, peppers, cucumbers, squash, and eggplants. Strawberries and tomatoes alone account for 40 percent of total pre-plant use of methyl bromide. Cucumber and squash are included in the model to reflect the impact that the ban will have on the double-crop production system employed in Florida, where these crops follow tomatoes or peppers. These crops are planted into the same plastic mulches as the first crops, thus benefiting from the fumigation of the first crops. The EPA has not authorized the direct use of methyl bromide on cucumbers or squash.

Several factors were considered to determine which production areas would be included in the model. The production regions that use methyl bromide were identified and included. Other production areas within the United States that do not use methyl bromide were included if in any one month they shipped at least 10 percent of the U.S. total shipments for that commodity according to the U.S. Department of Agriculture's Agricultural Marketing Service (AMS).[5] California, Florida, and Mexico were divided into regions to reflect differences in production practices and harvest dates. California has four regions: South Coast, Central Coast, Imperial Valley, and San Joaquin Valley. Florida has five: Northwest, Central, Southeast, Southwest, and Dade County. Mexico has two: Sinaloa and Baja California/Sonora. North Carolina, South Carolina, Georgia, and Texas are included as individual regions.

Harvested acres were based on three-year averages for crop years 1993–1994 through 1995–

[4] This data description condenses the details of the data collection and sources that can be found in Carpenter, Gianessi, and Lynch (2000).

[5] Determining if regions exist that could enter the market following the ban but that are currently not producing these crops is difficult. The horticultural industry has experienced a great deal of change in the last decade, in particular a shift to distribution by integrated growers/shippers. As the major buyers consolidate, they demand special packing, product differentiation, promotional support, and year-round supply (Wilson, Thompson, and Cook 1997). This demand has resulted in more vertical integration in the produce industry (Calvin and Barrios 1998). Therefore, even as certain regions' comparative advantage improves following the phaseout of methyl bromide, these regions may not be able to enter certain market windows. Increased competition from other regions such as Central America, the Caribbean, and Chile could also occur, but supply increases from these regions are not incorporated.

1996 [Florida Agricultural Statistics Service (various years), California Agricultural Statistics Service (various years), California Strawberry Commission (1998), Georgia Agricultural Statistics Service (1997), North Carolina Agricultural Statistics Service (various years), South Carolina Agricultural Statistics Service (various years), Texas Agricultural Statistics Service (various years)]. Monthly vegetable imports were averaged over a three-year period (U.S. Department of Agriculture 1997). Harvested acres for Sinaloa were obtained from a Mexican grower association, CAADES (Confederation of Agriculture Associations of the State of Sinaloa) (CAADES 1996). Mexican average yields by state were obtained from the Mexican Department of Agriculture (various years). Harvested acres for export from Baja and Sonora were obtained from a variety of sources [Cook et al. (1991), the Sonoran Growers' Association (various years), Mexican Department of Agriculture (various years)].

Demand parameters included flexibilities (Scott 1991, Spreen et al. 1995). Wholesale prices from the four representative markets—Atlanta, Chicago, Los Angeles, and New York—(AMS, various years) were used to compute average monthly prices over the three-year period. Average monthly arrivals over the three-year period were computed from arrival data (AMS, various years). Shipment data were used to determine the total demand in each market area. Arrival data were used to calculate the slope of the total demand curve; this data was adjusted to reflect the total demand in the market area in order to determine the demand curve intercept.

Transportation costs were determined by using distance from production region to market, obtained from Mapquest (http://www.mapquest.com/). The average per mile transportation cost was $1.31, derived from the "Fruit and Vegetable Truck Rate and Cost Summary" (AMS, various years).

Production and harvest costs were computed from the extension budgets of the various states. CAADES budgets from various years, Cook et al. (1991), VanSickle et al. (1994), and the Sonoran Growers Association provided the information used to generate costs of production for Mexican growers. Annual per acre yield estimates were computed from the three years of annual yields [Florida Agricultural Statistics Service (various years), California Agricultural Statistics Service (various years), California Strawberry Commission (1998), Georgia Agricultural Statistics Service (1997), North Carolina Agricultural Statistics Service (various years), South Carolina Agricultural Statistics Service (various years), Texas Agricultural Statistics Service (various years)].

All regions can use methyl bromide (pre-U.S. ban) or an alternative technology to produce crops. Exact figures on how much methyl bromide is used are not available, as growers can choose to do bed fumigation or full field fumigation. While the majority of growers follow the label rate, some growers alter the quantities. After interviews with extension personnel, growers, farm advisers, and chemical salespeople, the amount of methyl bromide used per acre was determined (Carpenter, Gianessi, and Lynch 2000). One alternative technology was determined for each crop/region combination. The alternatives for crops that currently use methyl bromide are presented in Table 1. Alternative technologies were determined through information obtained in journal articles as well as through interviews and workshops with growers, scientists, and farm advisers (Carpenter, Gianessi, and Lynch 2000). Alternative technologies chosen were those with the lowest per unit cost. The changes in preharvest costs are presented in Table 2, and percentage change in yield expected if methyl bromide is not used is presented in Table 3.

Information on Mexico was collected by faxing a questionnaire to key individuals involved in the horticultural industry in Mexico, asking them general questions regarding the use and cost of

Table 1. Alternative Pest Control Strategies to Methyl Bromide

Crop	Pest Control Alternative
Eggplant	Telone C-17 + Napropamide
Pepper	Telone C-17 + Napropamide
Strawberry	Telone C-17 + Napropamide in Florida Chloropicrin + Vapam in California
Tomato	Telone C-17 + Pebulate in Florida Vapam + Pebulate in Dade County, Florida Telone II in California

Table 2. Pre-Harvest Cost per Acre With and Without Methyl Bromide (MB) Technology

Region	Crop/rotation	With MB ($)	Without MB ($)	Region	Crop/rotation	With MB ($)	Without MB ($)
Florida (Central)	cucumber	n/a	2,208	*Florida (Dade County)*	squash	n/a	1,569
	squash	n/a	1,569		tomato	5,570	5,510
	strawberry	7,000	7,349		tomato/squash	7,433	7,373
	pepper/fall	6,357	6,380	*Mexico (Baja California)*	cucumber	2,500	2,000
	pepper/spring	6,357	6,380		eggplant	4,250	3,750
	pepper/squash	7,561	7,584		pepper	5,000	4,500
	tomato/cucumber	7,284	7,297		squash	1,549	1,049
	tomato/fall	5,995	6,008		strawberry	11,505	12,005
	tomato/spring	5,381	5,394		tomato	3,750	3,250
	tomato/squash	7,433	7,446	*Mexico (Sinaloa)*	cucumber	2,500	2,000
Florida (Southwest)	cucumber	n/a	2,208		eggplant	2,886	2,386
	pepper	6,357	6,380		pepper	2,197	1,697
	squash	n/a	1,569		squash	1,709	1,209
	pepper/cucumber	7,412	7,435		tomato	3,798	3,298
	tomato/cucumber	7,284	7,297	*California (Central Coast)*	strawberry	12,111	12,809
	tomato/fall	5,995	6,008		tomato	5,284	5,284
	tomato/spring	5,381	5,394	*California (South Coast)*	strawberry	12,111	12,709
	tomato/squash	7,433	7,446		tomato	5,284	5,284
Florida (Southeast)	cucumber	n/a	2,208	*California (San Joaquin Valley)*	tomato	5,284	746
	eggplant	6,224	6,247	*California (Imperial Valley)*	tomato	5,284	2,842
	pepper	6,357	6,380	*Texas*	pepper	1,020	520
	tomato	5,995	6,008	*Georgia*	cucumber	n/a	527
	pepper/cucumber	7,412	7,435		tomato/fall	2,317	2,330
	tomato/cucumber	7,284	7,297		tomato/spring	2,317	2,330
Florida (Northwest)	tomato/fall	5,746	5,759	*North Carolina*	pepper	1,386	1,409
	tomato/spring	5,746	5,759	*South Carolina*	tomato	3,950	3,963

Table 3. Annual Yield with Methyl Bromide (tons per acre) and Percent Adjustment with Alternative Pest Control

REGION	Crop	Rotation	Annual yield	Adjusted yield
Florida				
Central	cucumber		12.3	1
	squash		13.0	1
	strawberry		13.2	0.785
	pepper	fall	13.4	0.875
	pepper	spring	13.4	0.875
	pepper	pepper/squash	9.9	0.875
	squash	pepper/squash	11.5	0.825
	cucumber	tomato/cucumber	13.5	0.825
	tomato	tomato/cucumber	16.1	0.9
	tomato	fall	16.9	0.9
	tomato	spring	16.1	0.9
	squash	tomato/squash	11.5	0.825
	tomato	tomato/squash	16.7	0.9
Southwest	cucumber		13.0	1
	pepper		13.7	0.875
	squash		15.4	1
	cucumber	pepper/cucumber	13.1	0.825
	pepper	pepper/cucumber	10.6	0.875
	cucumber	tomato/cucumber	13.5	0.825
	tomato	tomato/cucumber	14.9	0.9
	tomato	fall	14.9	0.9
	tomato	spring	15.0	0.9
	squash	tomato/squash	15.4	0.825
	tomato	tomato/squash	14.9	0.9
Southeast	cucumber		13.0	1
	eggplant		12.5	0.85
	pepper		14.0	0.875
	tomato		16.1	0.9
	cucumber	pepper/cucumber	12.4	0.825
	pepper	pepper/cucumber	11.4	0.875
	cucumber	tomato/cucumber	13.5	0.825
	tomato	tomato/cucumber	16.1	0.9
Northwest	tomato	fall	16.0	0.9
	tomato	spring	16.0	0.9
Dade County	squash		13.4	1
	tomato		16.1	0.825
	squash	tomato/squash	13.3	0.78
	tomato	tomato/squash	16.2	0.825

table cont'd.

Table 3. Annual Yield with Methyl Bromide (tons per acre) and Percent Adjustment with Alternative Pest Control (cont'd.)

REGION	Crop	Rotation	Annual yield	Adjusted yield
Mexico				
Baja California	cucumber		10.4	0.95
	eggplant		7.1	0.95
	pepper		9.3	0.95
	squash		6.4	0.95
	strawberry		17.0	0.785
	tomato		19.3	0.95
Sinaloa	cucumber		12.8	0.95
	eggplant		13.3	0.95
	pepper		6.0	0.95
	squash		7.4	0.95
	tomato		14.3	0.95
California				
Central Coast	strawberry		21.0	0.785
	tomato		20.2	0.85
South Coast	strawberry		18.3	0.785
	tomato		21.5	0.9
San Joaquin Valley	tomato		13.9	0.82
Imperial Valley	tomato		15.0	0.82
Texas	pepper		7.4	0.875
Georgia	cucumber	fall	7.0	1
	cucumber	spring	7.0	1
	tomato	fall	15.9	0.9
	tomato	spring	16.0	0.9
North Carolina	pepper		2.3	0.875
	cucumber	fall	5.0	1
	cucumber	spring	5.0	1
South Carolina	tomato		17.8	0.9

methyl bromide there (Lynch 1996). Those contacted were also asked for names of other people or organizations who might provide information. If no response was received, a letter was mailed. Field interviews were used to complete the data collection. The interview team visited the Mexican states of Baja California, Sinaloa, Sonora, and Guanajuato during the fall of 1994 and met with government officials and producer associations. The team also visited growers at their farms. The team observed common cultural practices being used in Mexico by region and by commodity and collected accurate measures of the cost of production and yield effect of different practices. Methyl bromide was not used on a widespread basis except in Baja for strawberries. The cost differential was considered too high for the resulting yield augmentation; methyl bromide was therefore used on only a small percentage of the acreage in any one year. We assume a cost differential of $500 per acre when using methyl bromide for all crops except Baja strawberries, and a yield augmentation of 5 percent.

We analyze two cases—one with no land constraint and one limiting each crop to a 50 percent increase of the baseline acreage—following the imposition of the methyl bromide regulations in the United States. Given that land can be scarce, can be of limited fertility, or can have a high opportunity cost (for example, it can be sold for residential development), the 50 percent land constraint may actually be too lax, i.e., in the short run growers cannot expand acreage by 50 percent. In some regions, this constraint could represent the potential need for pre- and post-harvest resources such as cooling facilities and labor availability, or for learning how to grow the crop.

Results

The spatial equilibrium model was calibrated to establish the market baseline using GAMS Rev 119 software. The model estimates acreage planted by region, production system and pest control technology, monthly shipments from each region to each market by crop, and monthly sales for each crop by market. The post-ban results are compared to the pre-ban baseline. In addition to the baseline scenario, the following cases were analyzed:

(i) where the United States is limited to 0 percent of baseline methyl bromide usage; no land constraint

(ii) where the United States is limited to 0 percent of baseline methyl bromide; land in each crop is limited to 150 percent of baseline, i.e., only a 50 percent increase permitted on new land coming into production

The two cases reflect the total phaseout that was targeted for 2005 in the United States. These illustrate the longer-run behavior in the industry when critical use exemptions are no longer permitted. The 150 percent land constraint is meant to reflect possible short-run limitations to bringing new land into production.

Baseline planted acreage is shown in Table 4. The baseline acreage for all crops falls within 10 percent of the average acreage planted in these regions by crop for 1993–1996. Regions in which producers choose to use methyl bromide in the baseline results are the same regions where a majority of producers choose to use methyl bromide in reality. The only anomaly was California's Central Coast's choice to use methyl bromide on its tomato acres—in reality the majority of growers in this region do not employ this technology. Baseline methyl bromide usage on the set of crops considered is 10,330 metric tons.

Tables 5 and 6 show the planted acreage for the two post-ban cases. With few exceptions, the total production for each crop remains close to the baseline in each case, although production within and between regions has altered. In both cases, large shifts in crop acreage were found between regions, but in total the post-ban planted acreage does not change substantially. Exceptions are peppers, which exhibit a 14–18 percent increase in planted acreage in both cases, and strawberries, which show a 15 percent increase for case 1 and a 20 percent increase for case 2. In both scenarios, production of all crops increases in Mexico, with interregional shifts occurring in the United States. There are changes in the regions where production occurs.

With a total ban on methyl bromide imposed in the United States, with no constraint on acres planted (case 1), there is a great amount of region-shifting, both between the United States and Mexico and within the United States. Surprisingly, Mexico does not switch to methyl bromide for any crop (it does continue to use methyl bromide for Baja strawberries), indicating that the additional cost to use the technology ($500 per acre) outweighs the yield enhancement (5 percent). Eggplant production ceases entirely in the United States, offset by a 48 percent increase in Mexican production. Pepper production sees interregional shifting within Florida, and an increase in production in Texas (a non-methyl bromide user) and Mexico. Squash exhibits similar characteristics. The most striking result is that Baja increases strawberry acreage tenfold. As Baja increases its strawberry acreage, California strawberry growers decrease production. Tomato production shows shifts of production from methyl bromide using regions to non-methyl bromide using regions (Imperial Valley, Georgia, and Baja).

For case 2, there is a total ban on methyl bromide in the United States and a 150 percent limit on acres planted. With the available land limited, we see a similar overall shift in production to Mexico. Squash production shifts entirely to Mexico, except for that in Central Florida, where it increases by 13 percent. Southeast Florida tomatoes increase the allowable 50 percent.

Table 4: Baseline Planted Acreage, by Region and Crop

	Crop											
	Cucumber		Eggplant		Pepper		Squash		Strawberry		Tomato	
REGION	Total	Methyl bromide	Total	Methyl bromide	Total	Methyl bromide	Total	Methyl bromide	Total	Methyl bromide	Total	Methyl bromide
Florida												
Central[a]	3,710	3,710			3,784	3,784	1,971	1,567	5,066	5,066	15,813	15,813
Southwest[b]	2,695	0			8,199	8,199	3,351	552			18,604	18,604
Southeast	4,812	0	1,473	1,473	6,815	6,815					5,393	5,393
Northwest											2,189	2,189
Dade County[c]							6,267	1,398			4,164	4,164
California												
Central Coast									11,172	11,172	2,435	2,435
South Coast									11,950	11,950	3,975	3,975
San Joaquin Valley											32,556	32,556
Imperial Valley											1,580	1,580
Other U.S.												
Texas					4,627	0						
Georgia	12,600	0									4,353	4,353
North Carolina	5,985	0			6,418	6,418						
South Carolina											3,850	3,850
Total U.S.	29,802		1,473		29,843		11,589		28,188		94,912	
Mexico												
Baja California	3,825	0	267	0	4,605	0	5,320	0	1,310	1,310	12,588	0
Sinaloa	7,978	0	2,191	0	9,554	0	8,574	0			26,628	0
Total Mexico	11,803		2,458		14,159		13,894		1,310		39,216	
Total acres planted	41,605		3,931		44,002		25,483		29,498		134,128	

[a] Includes 3,710 acres in tomato/cucumber rotation, 300 acres in pepper/squash rotation, and 1,267 acres in tomato/squash rotation.
[b] Includes 552 acres in tomato/squash rotation.
[c] Includes 1,398 acres in tomato/squash rotation.

Table 5. Planted Acreage, Post-Ban, by Crop and Region (no land constraint)

	Crop					
REGION	Cucumber	Eggplant	Pepper	Squash	Strawberry	Tomato
Florida						
Central	3,816		2,958	5,401	5,497	13,693
Southwest	2,469		14,474			17,537
Southeast	4,787	0	0			9,614
Northwest						384
Dade County				5,986		2,473
California						
Central Coast					5,247	0
South Coast					8,223	0
San Joaquin Valley						31,666
Imperial Valley						3,830
Other U.S.						
Texas			8,100			
Georgia	13,263					9,404
North Carolina	5,920		6,569			
South Carolina						1,545
Total U.S.	30,255	0	32,101	11,387	18,967	90,146
Mexico						
Baja California	3,994	282	4,588	8,543	14,693	21,834
Sinaloa	8,219	3,362	15,367	7,741		28,591
Total Mexico	12,213	3,644	19,955	16,284	14,693	50,425
Total acres planted	42,468	3,644	52,056	27,671	33,660	140,571

Monthly price changes ranged from a decrease in the price of cucumbers of -0.7 percent to an increase in the price of strawberries of 20 percent, both in the Los Angeles market (Table 7). Cucumbers had the least fluctuation in price, followed by tomatoes. Strawberries had the largest price increases (16.5–20 percent) in all the markets, followed by peppers (7.1–17.1 percent). These price increases negatively affect consumers but benefit growers.

On the consumption side, given the price increase, we find that consumer surplus declines for each crop when a methyl bromide ban is imposed (Table 8). The overall surplus ($3.5 billion) decreases $107.2 million under the no land constraint case, and $133.6 million with the land constraint. Changes range from virtually no decline for cucumbers and squash (crops that do not use methyl bromide except in the double cropping system) to 7.9 percent for strawberries, for which all regions in the United States and Mexico use methyl bromide. Strawberries account for the majority of the decreased surplus.

Methyl bromide use decreases substantially. The baseline U.S. methyl bromide use is 10,330 metric tons, with Mexico using only 117 metric tons. Without the land constraint, Mexico's total methyl bromide use is 1,309 metric tons, far less than the amount eliminated from use in the United States. Post-ban, Mexico responds by increasing production, but does not increase its use of methyl bromide significantly. U.S. regions that do not use methyl bromide before the ban also increase acreage. The 1,309 metric tons is less than the current limitation of 1,885 metric tons that Mexico has agreed to abide by. However, if

Table 6. Planted Acreage, Post-Ban, by Crop and Region (150 percent land constraint)

	Crop					
REGION	Cucumber	Eggplant	Pepper	Squash	Strawberry	Tomato
Florida						
Central	3,856		3,494	2,227	6,285	15,370
Southwest	2,458		12,298	3,290		19,579
Southeast	4,801	0	2,506			8,089
Northwest						2,412
Dade County				5,607		1,767
California						
Central Coast					12,560	0
South Coast					14,568	0
San Joaquin Valley						34,534
Imperial Valley						2,371
Other U.S.						
Texas			6,941			
Georgia	13,236					5,733
North Carolina	5,919		6,569			
South Carolina						3,416
Total U.S.	30,270	0	31,808	11,124	33,413	93,271
Mexico						
Baja California	3,983	373	4,644	7,979	1,964	18,881
Sinaloa	8,218	3,287	14,331	8,033		28,942
Total Mexico	12,201	3,660	18,975	16,012	1,964	47,823
Total acres planted	42,471	3,660	50,783	27,136	35,377	141,094

Mexico is currently using the 1,885 metric tons for other purposes beside these horticultural crops, these crops will have to outbid the other users to obtain the rights to use the methyl bromide.

While Mexico's post-ban methyl bromide use does not increase significantly in the model, a reduction in the assumed cost differential of $500 per acre between methyl bromide and alternative technologies or an improvement of yield using methyl bromide greater than 5 percent could elicit additional adoption. For example, if using methyl bromide cost only $400 more per acre and the yield augmentation remained 5 percent, Mexico would adopt methyl bromide on all planted crops except cucumbers and squash following the ban, even though baseline use remained the same at 117 metric tons. This would increase Mexico's methyl bromide use to 6,404 metric tons, substantially more than the pre-ban baseline of 117 metric tons. Even with this higher level of adoption, use in North America overall would still be reduced by almost 4,000 metric tons following the ban.[6] Similarly, if using methyl bromide technology cost $500 more per acre and the yield augmentation was 20 percent, Mexican producers would adopt the methyl bromide technology after the ban. Under this scenario, fewer acres would be planted, as yield would be 20 percent more per acre, and Mexico methyl bromide use would increase to only 4,027 metric tons.

[6] Mexico is currently limited to 1,885 metric tons of methyl bromide under the Montreal Protocol. Therefore, using 6,404 metric tons or 4,027 metric tons would violate its quota limitation unless it obtained critical use exemptions. Until 1997 however, Mexico had no restriction on use, and if it had begun to employ this level at that time, that could potentially have been incorporated into Mexico's baseline quota.

Table 7. Average Monthly Price Changes, by Crop and Market (150 percent land constraint)

	Cucumber	Eggplant	Pepper	Squash	Strawberry	Tomato
Atlanta	1.3%	8.1%	11.6%	4.2%	17.1%	3.7%
Chicago	1.1%	1.2%	7.1%	1.6%	17.1%	2.8%
Los Angeles	-0.7%	1.0%	17.1%	0.1%	20.0%	0.4%
New York	1.4%	7.5%	9.4%	4.0%	16.5%	3.6%

Table 8. Change in Consumer Surplus (pre-ban total $3,503,962,815)

	No land constraint	150% land constraint
Cucumber	-0.8%	-0.8%
Eggplant	-3.8%	-4.5%
Pepper	-1.7%	-1.8%
Squash	-1.3%	-1.3%
Strawberry	-5.9%	-7.9%
Tomato	-1.5%	-1.7%
Total change	$107,181,393	$133,575,675

Conclusions

These results indicate how, given certain assumptions and the computed baseline, the horticultural sector will change once methyl bromide becomes unavailable in the United States. These results support scenario 2, outlined in the introduction. Production shifts to Mexico, methyl bromide use decreases overall, domestic production decreases overall, and domestic prices increase. This suggests that the environmental goal of reducing methyl bromide use will be achieved and that a pollution haven in Mexico will not be created unless the cost differential is less than and/or the yield improvement is greater than expected. However, if the cost differential is less than and/or the yield improvement is greater than expected, why is Mexico not currently adopting methyl bromide on a broader scale, that is, why does it use so little in the baseline? While the assumed change in yields and costs is an attempt to look beyond a one-year horizon, these results do not reflect long-run adjustments that may be made in an industry. For example, if growers were to shift to green beans, which were not one of the crops considered in the model, the model would reflect only that the acreage had gone out of tomatoes—it would not reflect the additional net revenue that may be gained from green bean production. Similarly, under the case of no land constraint, prices would increase by a smaller amount, decreasing the impact on consumers and increasing the impact on producers. Likewise, if a region not included in the model were to enter the market in these months, the model might overestimate the effect on consumers and underestimate the effect on producers.

The results show that the ban on methyl bromide will shift production location to some degree but will not increase methyl bromide use in Mexico dramatically. Some regions will find that it is no longer profitable to continue producing the crop at the same acreage as they did before the ban. Other regions will find that their relative comparative advantage has increased and they will actually increase production. Since some regions in California, Texas, and Mexico do not use methyl bromide, their costs and expected yields should not change. In most cases, they are able to respond by increasing production; a few regions increase production of certain crops until they hit the land constraint. Therefore, we see a situation where the environmental regulation shifts production to "less" polluting regions, assuming that ozone depletion is the only pollutant of concern. The change in quantity and thus the change in price depend on impacts in competing regions and the assumed demand flexibilities. While all the flexibilities assume that the percentage change in price will be less than the percentage change in quantity, the resulting change in price is sometimes sufficient to cover the increased cost of the alternative pest control.

Given that the major impact of the regulation is borne by consumers, the relevant question is whether the benefits of less methyl bromide use and less ozone depletion are greater than the additional costs consumers will incur for the affected fruits and vegetables. At this time, little information is available to assess this trade-off calculation. Similarly, the identified alternatives may have their own environmental costs: the overall decrease in ozone depletion may be offset by increased water quality problems, for example.

While the phaseout of methyl bromide importation and production in the developed world was scheduled to be completed by 2005, the critical use exemptions granted for U.S. producers and others for 2005 indicate that methyl bromide continues to be used. The United States plans to request exemptions for 2006 as well. Although it has decreased its use of methyl bromide by 31.7 percent between 1991 and 1999, it continues to account for 92 percent of the North American methyl bromide use (EPA 2002). As the phaseout has progressed, the price of methyl bromide has increased from $2.28 per pound in 1993 to $5.32 in 2002, a 133 percent increase (National Agricultural Statistics Service, various years), inducing many producers to shift to alternative pest control or to use less methyl bromide in the mix of chemicals employed. As mentioned above, Mexico has agreed to limit its use to its 1995–1998 average use level. Under the baseline assumptions of the model, Mexico will increase its use, but not beyond the permitted amount. However, we do find that if methyl bromide cost only $400 more per acre than not using it, instead of the $500 more per acre assumed in the model, and if the yield augmentation were 5 percent, Mexico would adopt methyl bromide on all planted crops except cucumbers and squash following the ban in the U.S., increasing Mexico's methyl bromide use to 6,404 metric tons. Similarly, if the cost differential were $500 and the yield augmentation were 20 percent, we find that Mexico would increase its methyl bromide use to 4,027 metric tons. However, even if the cost differential and/or yield augmentation justified additional methyl bromide adoption, in order to increase its use levels Mexico would have to either seek exemptions from the Protocol parties or be in noncompliance with its treaty obligations.

This model and empirical approach can be used for other trade and environment issues in which the technology adoption decision is made based on heterogeneous factors like pest pressure, land quality, capital availability, degree of skilled labor, etc., and where differing regulations are imposed. In this case, we demonstrate that a pollution haven is not created in one country as the result of a pre-existing, more stringent regulation in another, but the converse could equally be true. Similarly, the model could be employed to analyze the differential effects of another pesticide regulation on different regions where pest pressure and growing conditions may vary.

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