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Public Open Access and Private Timber Harvests: Theory and Application to the Effects of Trade Liberalization in Mexico

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Abstract. A common popular assertion is that trade liberalization encourages deforestation. But whether this is true depends on how trade policies affect the allocation of land among competing uses and how they influence illegal cutting of public forests. A model is presented that allows for forests to be either public or private, and public forests are divided into protected (or managed) and threatened categories. Effects of price changes are shown on each part of the forest. An empirical version of the model is applied to the case of Mexico with NAFTA. Most scenarios considered show that NAFTA will have positive long-run effects on forest cover in Mexico but that this is net of losses on private lands.

Key words: deforestation, forests, land quality, land-use choice, NAFTA, ownership heterogeneity,

JEL classification: F 15, F 14, Q23, Q24, R 14

1. Introduction

During the past decade, many countries, particularly those in Latin America, have switched from an industrial policy of protection of import-competing industries to one of open markets. The apparent recognition by these governments is that rationalization of input use, freer expression of comparative advantages, and the consequent increased access to foreign markets, will provide long-term economic gains. Rationalization of input use implies changes in input prices. A common assertion, however, is that the changing prices from freer markets will mean more rapid destruction of forest resources.

Trade expansion as a result of NAFTA, GATT, and other arrangements, is likely to change many of the determinants of domestic demand and supply of forest products. Hence, it is possible that the trade expansion could result in higher rates of deforestation and forest degradation, as total industrial output and consumption increase and as international trade becomes easier, although this issue is not settled (e.g., Vincent 1990, 1992; Primo Braga 1992; Barbier et al. 1995a, b; Barbier and Burgess 1997; Deacon 1995). Further, the welfare gains from trade expansion might also result in increased demand for environmental amenities, implying that a complex dynamic between trade policy and deforestation might exist (Tomberlin et al. 1998).

While modeling of the relationship between trade and deforestation is growing in popularity (e.g., Southgate 1990; Deacon 1994, 1995; Barbier and Burgess 1997), few have approached the issue of trade's links to deforestation from a resource economics perspective. In particular, only Barbier and Burgess (1997) describe a relationship between trade and land use decisions, and only a few (e.g., Barbier and Burgess 1997; Hardie and parks 1997) have attempted to describe how the distribution of land qualities and ownership characteristics affects the amount of land devoted to forest. Yet in many cases understanding such heterogeneity in natural resources and ownership is important for understanding the spatial, ecological, and economic effects of policies.

This paper describes a model of land use under ownership and land use heterogeneity, and an empirical version of the model is used to predict the effects of the North American Free Trade Agreement (NAFTA) on Mexico's forests. The theoretical model expresses timber output and the amount of land devoted to forest as a function of the net returns to alternative uses, the tenure of the land, and the amount of control that governments have over that land. Land is allocated among competing uses according to private optimal behavior, not public optimal behavior (e.g., Barbier and Burgess 1997). Different from previous analyses, this model organizes land use choice as the sum of decisions by three groups, each group facing a different set of variablesin the decision.

The remaining paper is organized as follows. Model development begins with a review of the relevant literature. This leads to an explanation of the decision models used by private forest owners and cutters of open-access forests. Included in these parts are explanations of the responses of each ownership to changes in timber prices. Next, using the theoretical results shown in preceding sections, I describe an empirical model of forest cover and employ it to make informed guesses on the effects of freer trade on deforestation in Mexico. I conclude with a review of findings and propose avenues for further research.

2. Methods

Nearly all research into deforestation starts from an assumption that forest cover is determined only on publicly-held open-access lands that are subject to unregulated invasions by agricultural colonists. No role is given to the private forest land owner in these analyses, even though it is recognized that an active timber market can help to build a private forest estate (Hyde 1980; Parks and Murray 1994; Plantinga 1996). These omissions, valid or not for the countries examined, are common to both general equilibrium and partial equilibrium modeling of deforestation.

In many models, timber price changes are viewed as only negatively affecting forest cover, at least in the tropical countries where much modeling has focused. For example, Deacon's (1995) general equilibrium model of deforestation links deforestation with policy instruments, including trade instruments. Forests are described as open-access, nonrenewable, and having no market value as sustained productive units. For a private individual or firm, while potentially generating revenue from forest removal, only the land upon which forests grow is a valued sustained input in the economy. Higher wood prices only serve to accelerate forest liquidation.

Partial equilibrium efforts to explain deforestation model land use choice, and these include works by Southgate (1990) and Barbier and Burgess (1996, 1997). Southgate (1990) ignores private timber owners, beginning from an assumption that deforestation is driven by agricultural colonists, who do not manage forest for timber and rarely have land titles at the margin of agricultural frontiers. Land use decisions in this group are choices between crop production and erosion control. Land users optimize inputs of labor and capital, resulting in privately optimal but implicitly publicly sub-optimal land use mixes.

Barbier and Burgess (1996) examine Mexico's rate of agricultural area expansion and tie it statistically to agricultural prices and population pressures. These results are extended to analyze the potential long-run responses of NAFTA-induced changes in macroeconomic and agricultural variables on deforestation. The role of private timberland owners is not addressed. Barbier and Burgess (1997) approach land use from a perspective of public optimization, describing the conditions for optimal forest cover. While their model derives from a private optimization model, it includes public amenity values in the optimization problem. Their model therefore can be used to describe the degree to which actual land use patterns differ from optimal patterns.

2.1. PRIVATELY OWNED FORESTS

In the model presented here, forest owners include private landowners and the government, and each group responds differently to market forces when making land-use decisions. Private landowners retain complete control of their land and have paid full market value for their property. Their decision is how to employ land in order to maximize land value by comparing the discounted value of all future revenues and other benefits net of costs from either forest or nonforest uses.

Consistent with the works by Faustmann (1849), Hartman (1976), Samuelson (1976), Hyde (1980), and Comolli (198 1), the landowner maximizes the soil expectation value of the land. The land-use decision of a private landowner therefore depends on the economic returns possible from investing in another enterprise on the same unit of land or investing capital elsewhere. Land use alternatives include growing timber for wood outputs or using the land for other purposes. This value is calculated for forest and nonforest alternative uses and compared. In forest use, the first order conditions from maximizing the optimization criterion, V, provide the optimal rotation length (T^*), optimal input combinations (*), and optimal output quantities (q^*, u^*). These optimal levels are expressed as a function of the following: the alternative rate of return r, the annual rate of returns from comparably risk-adjusted non-land investments; the prices of the wood output (P) and production inputs (w); the unchangeable land characteristics or land class metrics (U), which may include variables such as slope, aspect, soil characteristics, or rainfall, that affect the value of the private nontimber forest benefits, u; and the costs of timber production (wL) – which include transport costs, related to distance to roads or markets (Nelson and Hellerstein 1997) – and forest management (k). Note that the bundle of private nontimber forest benefits, u, has a price normalized to unity. Also, note that U may affect optimal input combinations – L(U), k(U). Finally, forest management costs might be a function of prices themselves, if forests are subject to unauthorized invasions; in that case, k would be $k(U, P, A)$, where A are prices of commodities produced by competing nonforest uses of the land. Here, management costs would vary with prices of outputs. For now, we assume that management costs are independent of these prices.[1] The augmented Faustmann (1849) problem is then:

$$\max_{T,L} V = \frac{[Pq(T, L; U)e^{-rT} + \int_0^T u(v; U)e^{-rv}dv - wL(U) \quad k(U)]}{1 - e^{-rT}} \tag{1}$$

As shown, it is clear that (1) is increasing in P, for $0 < r < 1$ (see Hyde 1980, p. 64). Expressing a derivative as a subscripted variable, among the first order conditions is that associated with rotation length, T:

$$Pq_T + u(T^*; U) = rPq^*(T^*, L^*; U) + rV^*_{\text{For}} \tag{2}$$

where

$$V^*_{\text{For}} = \frac{[Pq^*e^{-rT^*} + \int_0^{T^*} u(v; U)e^{-rv}dv - wL^* - k]}{1 - e^{-rT^*}} \tag{3}$$

is the market value of forestland with characteristics U. This shows that the marginal revenue of timber plus the value of private nontimber forest benefits in year T^* must equal the sum of the opportunity costs of holding capital (timber and land). Inputs are determined by the first-order condition defined by the derivative of (1) with respect to inputs, L:

$$Pq_L(T^*, L^*; U) = we^{rT^*}. \tag{4}$$

Thus, the optimal quantity of inputs is set where the marginal value of timber produced from the last unit of input equals its marginal cost.

If factor markets are not perfectly competitive, then (1) will not apply strictly. Still, the optimal harvest period will be where the period's costs – perhaps determined with higher-than-soil expectation value land prices, stemming from an imperfect land market – equal the value of the additional revenue and utility produced by the stand in that period.

An implication of (2), given that product and factor markets are perfectly competitive (see Hyde 1980), is that if the sum of current nontimber forest benefits and marginal timber value is always greater than capital and land costs, then the land will be employed in forest and will never be harvested (Hartman 1976). Thus, forestry returns are never maximized and (2) never holds as an equality:

$$\text{if } Pq_T + u^*(T^*; U) - rPq^*(T^*, L^*; U) - rV^* > 0 \text{ for all } T \geq 0 \text{ then } T^* = \infty. \quad (5)$$

It is also possible for (2) to hold only trivially, so that the inequality in (5) is reversed:

$$\text{if } Pq_T + u^*(T;U) - rPq(T, L; U) - rV^* < 0 \text{ for all } T \geq 0 \text{ then } T^* = 0. \quad (6)$$

Inequality (6) would apply to any combination of several reasons, including the case where $V^* = V^*_{\text{NF}}$. The statement that $T^* = 0$ implies that, given prices (including the alternative rate of return) and alternative land uses, the net returns to land in forest are negative. Thus, inequalities (5) and (6) describe the extremes, both precluding active timber management but implying radically different land uses. Land use choice – forest versus nonforest given prices and land characteristics (and, implicitly, the biological growth function for forests growing on such land) – for the private landowner is only determined by whether or not (6) is true. If (6) is true, then the land is not employed in forest; if (6) is not true (i.e., if (2) or (5) hold), then the land is employed as forest.

As described, V^* is a function of prices and land characteristics: $V^*(P, A, r, w; U) = \max[V^*_{\text{For}}(P, r, w; U), V^*_{\text{NF}}(A, r, w; U)]$. This list of variables important to the private land use decision therefore can accommodate price-varying management costs, $k(U, P, A)$, where $\partial k/\partial P \geq 0$ and $\partial k/\partial A \geq 0$. Such a function as V^* defines the extensive margins for forests on private land and is where the level of U is just sufficient to make (5) an equality (Hyde 1980, p. 51). The land use choice is described graphically in Figure 1. Here, on the vertical axis is the rent accruing to forest (V^*_{For}) and nonforest uses (V^*_{NF}), and on the horizontal axis is land use class, a continuous variable (but indexed by an integer, 1-6). Nonforest uses yield the highest rents in land class 1-3, but forest uses yield the highest rents in land classes 3-5. An increase in the price of the forest product might cause a shift upward in the V^*_{For} surface, expanding the margins of optimal land use in forestry to include land quality classes 2 and 6, thereby increasing the area of land devoted to forestry and decreasing the area of land devoted to nonforest uses.

The equilibrium land area of privately owned timber, F_{pr}, is a positive function of a constant quantity of private land (H), a positive function of the price of timber, a negative function of nonforest use output prices, a negative function of the alternative rate of return, and a positive function of nontimber forest benefits. We

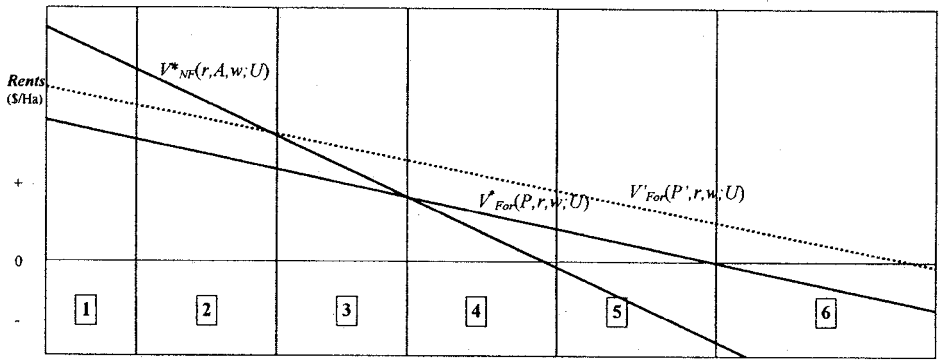

Figure I. Two possible profitable active land uses are considered: nonforest uses and Land Quality Class (U) forestry. Rents, V^*_{For} and V^*_{NF}, are functions of product prices (P or A, a non-land alternative rate of return, r, that is adjusted for risk and timing of investment returns, and land quality (U). As shown in dark lines, in land quality classes 1-3, nonforest rents exceed forestry rents **but** forestry rents are still greater than zero. In the land quality class 4, nonforest use still would return positive rents but profits from nonforest enterprises would be negative because land rental charges would be too high; further, forestry would return higher rents in classes 4 and 5, so that the land should be devoted to forestry. Finally, in land quality class 6, neither forestry nor nonforest uses return positive rents. Hence, this land class remains in its natural state and, in this two profitable land uses world, free. Because V^*_{For} increases in P, an increase in P, an increase in P would shift V^*_{For} upward and expand land area devoted to forest to include land quality classes 3 and 6.

can obtain aggregate forestland area by summing across all landowners ($i = 1$ to I) the proportion of each landowner's property, g_i, where the land's highest flow of benefits is in forest. Letting Pr[$V_i^* = V^*_{i.\text{For}}$] = $g_i(P, A, r, w; U_i)$, *we* have

$$Y = \sum_{i=1}^{I} g_i(P, A, r, w; U_i) = \gamma(P, A, r, w; U) \in [0, 1]. \tag{7}$$

Therefore, the total area of private forestland in a country is expressed as a function of Hand y:

$$F_{\text{pr}} = H \cdot \gamma(P, A, r, w; U). \tag{8}$$

And as implied by Hyde (1980), the derivative of F_{pr} with respect to the forest product price, is positive: $\partial F_{\text{pr}}/\partial P = H\partial y/a P > 0$, since H > 0 and ∂ y/a $P >$ 0. Similarly, $\partial F_{\text{pr}}/\partial A = H\partial\gamma/\partial A < 0$. These conditions hold if the costs of management are second-order compared to the total benefits from forest. That is, if $k(\cdot) = k(U, P, A)$ increases faster in P than benefits net of other costs, then, at least beyond some range, the effects of price changes on private forestland area are negative.

2.2. PUBLICLY-OWNED FORESTS

Public forests are subdivided into two components, and the mix of these two components is important in determining the rate of deforestation. These are: (i) the portion regulated by some managing agency, so that all decisions made regarding timber cutting and domain disposal are made by a government body, and (ii) the portion unregulated and therefore open to unauthorized timber cutting (i.e., the 'open access' portion of the forest). In the latter portion, the decision-makers regarding land allocation are members of the general public – potentially, invaders of public lands that decide whether to cut the forest or not. Changes in prices and policies may have differing short- and long-run effects on timber inventories and on any wood supply deriving from each of the two components. The regulated portion of public forests and their outputs in this model are assumed to be invariant to price changes in the short- and long-run because government agencies are assumed to have predetermined output (harvest) levels scheduled for the public forests under their control. More important, these lands are assumed to remain to forest, and any harvests are strictly regulated such that the forest is maintained or regenerated after harvest. The unregulated part of public forests provide a more price-elastic short-run supply because long-term management issues (or opportunity costs) here play no role in determining the amount of cutting. Invaders of these public forests make harvests that result in a permanent loss of forest. Obviously, invaders do not necessarily destroy forest forever, but it seems reasonable to presume that cutting eventually leads to a substantial reduction in the services deriving from forests, especially those deriving from primary forests.

The amount of unregulated forests in public ownership is determined by land quality, the threat of penalties for illegal harvests, the prices of harvest inputs and outputs, and any future benefits derived from use of that land by the harvester. The harvest (i.e., deforestation) decision for stand j, h_j, is:

$$\text{if } h_j = P_t q_j(U_j) - w_t' L_j(U_j) - \delta M + B(A, r, w; U) > 0 \text{ then } q^*_{j,t} = q_j \qquad \text{else } q^*_{j,t} = 0 \tag{9}$$

where δ is the probability of being caught and fined for cutting the stand, M is the fine assessed per unit of quantity for being caught cutting the stand, B are benefits derived from conversion itself (i.e., net benefits accruing to the cutter from use of the land in nonforest uses, so that $\partial B/\partial A > 0$), and other variables are as previously defined. If the benefits from cutting stand j in year t are greater than the expected costs, then the stand will be cut. If prices vary substantially over time, then the amount of illegal cutting should vary substantially, consistent with the price variability.

In our model, δ and M are price-invariant. But as implied by Swanson (1994), δ and M may also be a function of timber prices, wherein a government has a greater. incentive to patrol its forests and enforce its laws regarding illegal cutting when timber prices are high. This corresponds with a situation in which a government's investment (including protection and management) in the public forest resource is positively related to its value. In that case, if trade liberalization were to increase timber prices, for example, then the amount of illegal cutting would not increase as greatly as in the case where δ and M were price-invariant, since the government would spend more to protect the forest from illegal cutting. With this modification, the threatened share of public forests, described by equation (9), would not increase in price over the whole range of prices.

In year t, unauthorized cutting and permanent conversion of public forests occurs on a fraction, $\beta_t \in [0, 1]$, of the forested public domain, F_{pub}:

$$\beta_t = \sum_{j=1}^{J} Pr[h_j(P_t, A, r, w, \delta, M; U_j) > 0] \tag{10}$$

so that β_t is increasing in P and A. The quantity of forest remaining after one year is thus a multiple of this fraction and is increasing in P and A:

$$F_{a,t} = (1 - \beta_t) \cdot F_{\text{pub},t} = F_{\text{pub},t} \cdot [1 - \beta_t(P_t, A, r, w, \delta, M; U)]. \tag{11}$$

After some period, say T years, the amount of remaining forest is:

$$F_{a,t+T} = F_{\text{pub},t} \; . \; \Pi_{t=0}^{T}[1 - \beta_{t+T}(P_{t+T}, A, r, w, \delta, M; U)]. \tag{12}$$

A reasonable approximation of (12) might be:

$$F_{a,t+T} = F_{\text{pub},t} \; . \; [1 - \beta^*(P, A, r, w, \delta, M; U)]. \tag{13}$$

where $\beta* \in [0, 1]$ is the total long-run proportion of the public forest estate that will yield positive expected net benefits for illegal cutting, given the mentioned factors. Again, β^* is increasing in P and A.

Special cases can be considered. For example, if all forests in public ownership have positive expected benefits from illegal cutting (that is, $\beta^* = 1$) then, $F_{a,t+T} = f_{\text{pub},t}[1 - 1] = 0$. Another case is where public forests are completely regulated, due to either low timber prices, high expected costs of being caught, or high extraction costs, so that $\beta^* = 0$. Here, the amount of public forest in T years is equal to the current area of public forests: $F_{a,t+T} = F_{\text{pub},t}[1 \quad 0] = F_{\text{pub},t}$.

As implied by the model presented, the determination of whether an invader of public forest is the economic actor on a specific portion of the publicly held forest is determined by forest and land characteristics and the policies of the government itself. The government, through its own efforts to enforce its control over the publicly held forest, determines partly the size of that portion that is open to successful invasion and timber cutting.

2.3. EFFECTS OF PRICE CHANGES ON TOTAL FOREST AREA

Total forest area is defined as the sum of private and public forests. As described in previous sections, changes in prices and enforcement of laws would affect this area. Among these are changes in levels of international prices or in tariffs or nontariff barriers applied to imports or exports. In the following discussion, price changes can be thought of as arising from changes in exogenous factors, including changes in tariffs and nontariff barriers.

The effects of a forest products price change on total forest area can be divided into short- and long-run components. Total forest area in the short-run is:

$$F_t = F_{a,t} + F_{\mathrm{pr},t} = F_{\mathrm{pub},t}(1 - \beta_t) + H \cdot \gamma_t. \tag{14}$$

A permanent change in timber price, obtained from a change in forest products prices, occurring in year t, engenders the following short-run response:

$$\frac{\partial F_t}{\partial P_t} = -F_{\mathrm{pub},t}\frac{\partial \beta_t}{\partial P_t} + (1 - z_t)\, H \cdot \frac{\partial \gamma_t}{\partial P_t}. \tag{15}$$

On public forests, under the specifications of this model, all change in forest inventory derives from the timber price change's impact on unauthorized cutting; hence, its effect on public forest area is negative, as explained earlier. Timber price changes affect private forest land area positively, but the change in one period may not be complete ($0 < z_t < 1$).

In the long-run, say T years in the future, the effect of a timber price change in year t is different because it can affect both the amount of public forest remaining and the amount of private land devoted 'to forestry. Assume that T years in the future, the amount of forest threatened by unauthorized cutters is nil because all of the threatened forest has been cut. Long-run forest cover is:

$$\begin{aligned} F_{t+T} &= F_{\mathrm{pub},t+T} + F_{\mathrm{pr},t+T} \\ F_{t+T} &= F_{\mathrm{pub},t} \cdot (1-\beta^*) + H \cdot \gamma_{t+T} \end{aligned} \tag{16}$$

A permanent timber change will therefore induce the following long-run change in forest cover:

$$\frac{\partial F_{t+T}}{\partial P} = -F_{\mathrm{pub},t}\frac{\partial \beta^*}{\partial P} + H \cdot \frac{\partial \gamma_{t+1}}{\partial P}. \tag{17}$$

The first term on the right-hand side is positive with a negative sign in front, and the second term, in the case where management costs are not affected by output prices, is positive. Therefore, the effects of a price change depend on the shares in public and private hands." If a nation's forests are virtually all public, then a price increase will increase deforestation; a price decrease will work to preserve public forests. If most forests are privately held, then the long-run effect on total forest area of a timber price increase is positive.

Table I. Direct and indirect effects of price changes on the amount of land in forest and the quantity of wood produced from public and private ownerships in both the short- and long-run

Ownership	Price change	Forest area		Timber supplied	
		Short-run	Long-run	Short-run	Long-run[a]
Private	Increase	+	+	±	± (+)
	Decrease	–	–	±	± (–)
Public-authorized	Increases	0	0	0	0
	Decrease	0	0	0	0
Public-unauthorized	Increase	–	–	+	0
	Decrease	+	+		0
Total	Increase	±	±	±	± (+)
	Decrease	±	±	±	± (–)

This table assumes no change in the land area of controlled public forest lands. Private long-run timber supplied is probably positively related to price.

[a] The change in parentheses applies if land area changes dominate average annual output per unit area changes.

Table I summarizes the partial equilibrium effects of a price change on forest area and on timber supply (described in the Appendix), disaggregated by major forest ownership group. Again, this table ignores the possibility that management costs increase with timber price and are high relative to the flow of benefits from forests. The table also ignores the general equilibrium effects of such price changes on the larger economy. The effects of timber prices on private forest cover are not totally certain, but it is shown in parentheses in the last column to be positive, which would occur if forest area changes dominate price effects on output per unit area (and management costs). Note that in all cases – short-run price decrease, long-run price increase or decrease – total effects of a price change cannot be predicted without detailed information on the mix of land qualities, ownership, public control, and the growth functions of individual forests. What remains is a set of empirical questions for a given economy, land, biological resources, and governmental structure.

A final note about timber production and forests. As demonstrated above, a permanent price increase might induce the accumulation of a larger forest area in the long-run. If this occurs, then it must come from an expansion of forest area on private lands that is larger than the loss of public forests. In many countries, the public domain contains at least some primary forests, and expansions of forest area on private lands must come from expansion of the area of secondary forests and tree plantations. Thus, some of the loss of public forests from a price increase might come from losses of primary forests. If public goods provided by primary forests are greater than those provided by secondary or plantation forests, and (or) if the psychic value of a loss of a public resource is much greater than an equivalent gain of a private resource (see Knetsch 1993), then the welfare effects of a price increase may be negative, even if the total amount of forest on private land increases substantially.

3. Application to Mexico and NAFTA

An application of the model described above is used here to estimate the long-run effects of price changes on forest area Mexico. We begin by recognizing that Mexico's land tenure arrangements are unique, making labeling of lands in Mexico as 'public' or 'private' ambiguous. This is because of the existence of *ejidos*, land areas with rights communally assigned. SEMARNAP (1996) states that about 80% of forests in Mexico belong to communities and *ejidos*. But the original and all subsequent versions of the Forest Law in Mexico assign control of those forests largely to the Federal Government of Mexico (SARH 1993; Diario Official 1997). Technically, then, these forests and decisions on harvests are in the control of the government, not the ejido or the community. Further, forests on ejido lands are required to remain in forest, even after a government-sanctioned harvest, although trees can be planted by the ejido for profit and use by the ejido on ejido lands that are not currently forest. Indeed, we might expect that a certain amount of ejido nonforest lands could be converted to secondary (or plantation) forests if prices increased, but the opposite would not apply if prices decreased.[3] Taken together, these laws imply that ejido and community forests in Mexico are under government control, and Forest Law in Mexico grants this authority. Even given changes embodied in the 1992 Agrarian Law in Mexico, wherein *ejido* members may obtain fee simple title to their lands and use them as they please, this privatization only applies to the nonforest portion of the ejido lands (Procuraduria Agraria 1995). For purposes of the empirical application of the land use model described above, then, we assume that the label of 'government' applies to the forests of these *ejido* and community forest lands.

The analysis of NAFTA's effects on forest area in Mexico begins by understanding that NAFTA has been predicted to affect prices of inputs and outputs important to both agricultural and forest products in Mexico. Consistent with the theoretical model described above, the empirical model for Mexico's long-run forest cover changes will depend on these prices.[4] And we would expect, given that some *ejido* lands are forest and given that individual *ejido* members and non-members may have incentives through existing laws to cut forests illegally (Ford 1999), public forests are subject to illegal cutting that is price-sensitive. The direct effects of agricultural and forest products prices on deforestation can be expressed mathematically as

$$\mathrm{d}F_{\mathrm{tot}} = -\frac{\partial\beta^*}{\partial P}\mathrm{d}P\ F_{\mathrm{pub}} - \frac{\partial\beta^*}{\partial A}\mathrm{d}A\ F_{\mathrm{pub}} + \frac{\partial\gamma}{\partial P}\mathrm{d}P\ H + \frac{\partial\gamma}{\partial A}\mathrm{d}A\ H. \tag{18}$$

In terms of elasticities, these are

$$\mathrm{d}F_{\text{tot}} = -\xi_P^\beta \frac{\mathrm{d}P}{P}\beta^* F_{\text{pub}} - \xi_A^\beta \frac{\mathrm{d}A}{A}\beta^* F_{\text{pub}} + \xi_P^\gamma \frac{\mathrm{d}P}{P}\gamma H + \xi_A^\gamma \frac{\mathrm{d}A}{A}\gamma H \tag{19}$$

where the elasticities, ξ_u^v are the elasticities of v with respect to a change u and other variables are as previously defined. The changes in relevant timber and agricultural prices arising from the altered trade policies will come from both direct and indirect sources: directly, through tariffs, and indirectly, through the effects on other inputs to production and consumption. Hence, any welfare changes resulting from NAFTA will be included in the price effects described in equation (19). Mexico's prices will be additionally affected by alterations in exchange rates and pre-tariff export prices. Timber and agricultural price changes, derived from equilibrium export supply-import demand conditions, are therefore described as

$$\frac{\mathrm{d}P}{P} = \xi_Y^P \frac{\mathrm{d}Y}{Y} + \xi_w^P \frac{\mathrm{d}w}{w} + \frac{\mathrm{d}T_P}{T_P} + \frac{\mathrm{d}E}{E} \tag{20}$$

and

$$\frac{\mathrm{d}A}{A} = \xi_X^A \frac{\mathrm{d}X}{X} + \xi_w^A \frac{\mathrm{d}w}{w} + \frac{\mathrm{d}T_A}{T_A} + \frac{\mathrm{d}E}{E} \tag{21}$$

where Y is the output of the timber consuming sector, X is the output of the agricultural product consuming sector, T_P and T_T are the relative distortions of domestic prices from international prices (resulting from trade and domestic policies) with respect to timber and agricultural prices, and $\mathrm{d}E/E$ is the NAFTA-induced change in the peso-to-dollar exchange rate.

With (19)–(21), we have an empirical model for estimating the long-run effects of changes in trade policies on the amount of forests. What is needed are eight elasticity estimates, estimates of the effects of the policy on forest product outputs and agricultural product demand, estimates of the current amount of public forest threatened with unauthorized cutting (β^*), the amount of private forests, γH, and the expected changes in relative timber and agricultural prices.

Empirical estimates of all of the parameters and variables shown in (19)–(21) were obtained from the literature on NAFTA and land use economics. Mexico's forest land base data were obtained from Segura (1998). Forecasts of changes in Mexico's wood products, pulp and paper, and agricultural sectors, the costs of inputs to production, and exchange rates derived from the three general equilibrium predictions of NAFTA's effects. These are referred to as Scenario 1, by Brown et al. (1992); Scenario 2, by Roland-Holst et al. (1992); and Scenario 3, by Hufbauer and Schott (1992) and Bachrach and Mizrahi (1992). These studies provided alternative scenarios of the effects of NAFTA on the Mexican, U.S., and Canadian economies. The scenarios are described in Table II.[5]

Two approaches on the effects of trade price changes on domestic timber prices were tested. One approach assumed, using information from Kravis et al. (1982),

Table II. Summary data for empirical analysis of forest loss in Mexico as a result of NAFTA

Percentage changes in	Macroeconomic scenario 1[a]	Macroeconomic scenario 2[b]	Macroeconomic scenario 3[c]
GDP	0.0	2.57	2.0
Capital cost	0.6	5.77	0.0
Wage	0.7	0.0	0.0
Exchange rate ($/peso)	0.3	2.96	29.0
output			
Construction	-0.33	1.80	7.41
Paper	-1.14	-0.30	9.68
Printing and publishing	-2.26	2.10	6.04
Producer Prices[d]	0.69	0.0	0.0
Timber Prices[e]	-16.5	-19.9	-54.0
Kravis et al. (1992) paper price	3.0	3.0	3.0
Kravis et al. (1992) wood price	0	0	0
Kravis et al. (1992) agricultural prices	0	0	0

[a] From the A-scenario in Brown et al. (1992).
[b] From Experiment 3 in Roland-Holst et al. (1992).
[c] Hufbauer and Schott (1992) and Bachrach and Mizrahi (1992).
[d] Estimated by Prestemon and Buongiorno (1996).
[e] Average, weighted by import shares, of estimates made by Prestemon and Buongiorno (1996).

that Mexico's domestic prices after NAFTA will simply approach international equilibrium prices. That is, domestic price distortions disappear under NAFTA. The Kravis et al. (1982) study, while somewhat dated, formed the basis for some general equilibrium modeling, including that of Roland-Holst et al. (1992). The other approach obtained weighted-average estimates of price elasticity changes, as estimated by Prestemon and Buongiomo (1996), and assumed that domestic timber prices changed in exactly the same proportion as the domestic prices for wood products and pulp. These effects might be considered as more consistent with the general equilibrium effects of NAFTA than the Kravis et al. (1982) study. Total forest product quantity of output changes in Mexico forecast by the general equilibrium models of NAFTA were weighted by the quantity proportion of timber output in Mexico consumed by the wood product sectors and the pulp and paper sectors in 1992 (FAO 1997). Under this second approach, agricultural output prices were expected to reach the international equilibrium, as given by Kravis et al. (1982) which was not too different from that shown by the CGE studies mentioned above.

The amount of uncontrolled public forestland before NAFTA is really unknown. But information exists on the amount of protected forest and the component of public forests considered to be commercial (Table III). If only protected areas are considered invulnerable to illegal cutting, then the amount of uncontrolled

Table III. Key Mexico forest statistics used in this study"

Variable	Area (million hectares)	Notes
Public forests, protected[b]	3.8	
Public forests, unprotected	43.2	Implied $\beta^* = 1 - (3.8/43.2) = 0.92$
Public forests, commercial[a]	16.5	Implied $\beta^* = 1 - (16.5/47.0) = 0.35$
Private forests	8.3	
Total private land area	23.9	Implied $\gamma = (8.3/23.9) = 0.35$

Sources: Segura (1998), FAO (1997).
[a] Segura (1988) reports 38% for all forests in Mexico, which is applied to the public portion here.
[b] From Table 3 in Segura (1998), including national parks, reserves, monuments, and flora and fauna protection zones.

public (*ejido*, state, and community) forests would be 92% ($\beta^* = 0.92$). If only unprotected commercial forestland (which does not include protected areas) were vulnerable to illegal cutting, then only 35% of these forests would be classified as threatened ($\beta^* = 0.35$). A compromise amount might be set at 60% ($\beta^* = 0.60$), but a sensitivity analysis is done that tests the effects of NAFTA given an area of threatened public forest at 30, 60, and 90%.

The most difficult matter in applying this empirical model involved obtaining valid estimates of the elasticities of land use with respect of domestic forest products and agricultural prices. For this, only a few relevant estimates were found in the literature. These included studies by Parks and Murray (1994), Plantinga (1996), Barbier and Burgess (1996), and Andersen and Reis (1997). Unless the distribution of land and biological characteristics within ownerships is rectangular, then these elasticities would be expected to vary by absolute level of forest considered, as illustrated in Figure 1. Because no information regarding the distribution could be found, a sensitivity analysis is provided that describes NAFTA's effects on Mexico's forest area changes under the range of elasticities estimated by these authors. The elasticity of forest area with respect to agricultural price was -0.3 to -0.4 for Mexico (Barbier and Burgess 199'6). Because uncertainty surrounds this estimate, and because the positive influence of timber prices for private forest owners were ignored by these authors, a sensitivity analysis is done, allowing it to range from -0.1 to -1. The positive effects of prices on building a timber estate have not been attempted for the tropics. But research exists for temperate areas, with elasticities ranging from 0.35 (Parks and Murray 1994) to 1 (Plantinga 1996). Again, a sensitivity analysis tests a range of possible values.

Estimates of the effects of NAFTA on forest area in two ownerships are provided in Tables IV and V. Table IV describes the predicted long-run effects of NAFTA on each ownership category, under two final equilibrium price scenarios, the three general equilibrium scenarios, three variations on elasticities, and the assumption that the pre-NAFTA long-run amount of threatened public forest is 60%. Table IV

Table IV. Summary of estimates of NAFTA's effects on Mexico's forests, in thousands of hectares, implied under three general equilibrium scenarios and under two assumptions on how NAFTA changes domestic prices

NAFTA's domestic price effect	Land use elasticities	Ownership	Estimated forest area changes (1,000 HA) under . .		
			Scenario 1	Scenario 2	Scenario 3
NAFTA removes distortions	0.5	Public	62	62	62
		Private	-18	-18	-18
		Total	44	44	44
	1.0	Public	177	177	177
		Private	-52	-52	-52
		Total	125	125	125
	2.0	Public	354	354	354
		Private	-104	-104	-104
		Total	250	250	250
Import price sets domestic price	0.5	Public	2,329	2,811	7,610
		Private	-684	-826	-2,235
		Total	1,645	1,986	5,375
	1.0	Public	4,657	5,623	15,220
		Private	-1,368	-1,651	4,470
		Total	3,289	3,971	10,749
	2.0	Public	9,314	11,245	28,203
		Private	-2,736	-3,303	-8,284
		Total	6,578	7,942	19,919

Scenarios are described in Table II.
β^* is set at 0.60.

therefore is counterfactual: what would be the effect of NAFTA in the long run, compared to a situation in which there were no NAFTA. As shown in the 'removes distortions' scenario, NAFTA is expected to result in a counterfactual (net) increase in the long-run quantity of forests in Mexico by tiny amounts – less than 1%, with positive effects on public forests and negative effects on private forests.

In the case where NAFTA causes domestic timber prices to equilibrate with international prices, the effects of the agreement are universally strong. Because prices are predicted to change so dramatically under this scenario, essentially all threatened public forests will be saved and all private forests will be converted to other uses under Scenario.3; the effects are still large but less dramatic under Scenarios 1 and 2. As given by the theoretical analysis presented earlier, the incentive

Table V. Estimates of NAFTA's long-run effects on Mexico's forest area – Variations on amount of control (β^*), import price sets domestic price, moderately elastic harvest responses to wood and agricultural price changes

NAFTA's domestic price effect	Threatened forest, β^*	Ownership	Estimated forest area changes 1,000 HA) under . . .		
			Scenario 1	Scenario 2	Scenario 3
	0.3	Public	2,329	2,811	7,610
		Private	-1,368	-1,651	4,470
		Total	961	1.160	3.140
	0.6	Public	4,657	5,623	15,220
		Private	-1,368	-1,651	4,470
		Total	3.289	3.971	10.749
	0.9	Public	6,986	8,434	22,829
		Private	-1,368	-1,651	-4,470
		Total	5,618	6,783	18,359

Scenarios are described in Table II.

to illegally cut public forests will diminish under the lower future timber prices. And conversely, the incentive to manage private land for forests will diminish, as the returns to forestry are less than those for nonforest uses for all private lands.

Table V presents the sensitivity analysis of the long-run threatened amount of public forests, β^* ranging from 0.3 to 0.9, assuming the scenario where NAFTA removes distortions and moderate elasticities of harvest with respect to prices. At the lowest level of threatened public forests, NAFTA is predicted to decrease deforestation 1.0 to 3.1 million hectares, mainly because so little public forest would benefit from a reduced threat, relative to the losses of private forest. With β^* of 0.9, NAFTA is shown to save 7-23 million hectares of threatened public lands from being deforested and encourage the liquidation of 1.4-4.5 million hectares of private forests.

There are several caveats. First, these estimates are unbounded – none of the estimates have confidence intervals, and one might conclude that all estimates provided in Tables IV and V have equal probability. Second, the analysis ignores the portion of private forest that becomes uneconomical to manage under NAFTA but still too expensive to convert to other uses. That is, if all potential nonforest uses of the land under the trees also have negative returns to owners, then they will become unmanaged but remain as forests. In that sense, it seems unreasonable to expect that privately owned forests could be liquidated completely in Mexico. Further, if it is true that management costs vary with prices, then lower timber prices would mean lower management costs and, hence, enhanced forest management opportunities in some places. Finally, if government protection of forests is positively related to timber prices, then the amount of public forest 'saved' by NAFTA in Mexico would not be as large as that shown in these tables.

Nonetheless, the general direction of the long-run effects of NAFTA in Mexico is clear in Tables IV and V: public forests will be less threatened under NAFTA, part of the private forest estate will be converted to nonforest uses, and the net effect of the agreement is to reduce the long-run loss of forests in Mexico. These results fit with some results by Barbier and Burgess (1996) and are consistent with the fact that Mexico is a net forest product importer that faces almost certain price reductions for many forest products as a result of NAFTA. These price reductions reduce the incentive to illegally cut public forests while simultaneously reducing the incentive to devote private land to forest cover and timber production.

As implied by these changes, and if forest area changes dominate any opposite unit area production changes, timber production in Mexico in the long-run will be more reliant on public timber than it would have been without NAFTA. In the short run, effects of NAFTA are more ambiguous: private forest harvests will rise, as some land is converted to more profitable nonforest uses, but harvests from public forests will fall, as incentives for illegal harvest decline. Short-run price changes, then, will depend on which effect dominates – the private liquidation rate or the public conservation rate. And these differing short- and long-run public and private responses imply strategies to minimize the rate of private losses given NAFTA. In particular, more efforts could be placed in increasing productivity from private forestlands, either through better programs of technology transfers or through subsidies.

4. Summary and Implications

The above analysis broadens the work of previous research, where deforestation has been modeled as a phenomenon of an open-access public domain, by including the possibility of private forest ownership and the possibility that part of the public domain is not open-access. Given the wealth maximization objective for private landowners, higher forest products prices can create the incentive to build a privately owned timber estate. Lower forest products prices, which may occur from trade liberalization in forest products importing countries, may mean slower deforestation on open-access public lands but also accelerated liquidation of private forest assets.

But exactly what are the effects to tariff protection for any particular country is an empirical question whose answer depends on ownership mix, land characteristics, the proportion of public domain threatened by unauthorized harvesting of public domain forests, and the effects of trade liberalization on other parts of the economy. The effects of policies and market signals on deforestation rates, then, are questions perhaps best investigated at the level of a single country, not across many countries. At a minimum, cross-country statistical models of deforestation should account for variations in ownership mix, the degree of government control over public forests, and biophysical characteristics of land resources.

The models of forest cover and timber supply presented above reveal how government policies, including trade policies, can affect long-run inventories and the rate of loss of forests in the public and private domain. Trade liberalization, which usually brings price changes in multiple products, can also affect the quantity of land devoted to forest by affecting returns in alternative land uses and costs of forest management and harvest. Governments can also affect the risk of being charged for unauthorized cutting (δ) and the costs of being caught (M), and adjusting these risks and costs, consistent with the price and welfare effects of trade regime changes, would be rational (Swanson 1994). Governments may adopt policies and strategies that can increase the returns to timber management (such as interest subsidies) and returns to activities' considered alternatives to unauthorized cutting or which further decrease pressure to convert forests, such as irrigated agriculture (Barbier and Burgess 1996).

This paper highlights avenues for related empirical research. One is to estimate short- and long-run timber supply equations by ownership, conforming to the functional forms described above. This would account for asymmetric price responses by different categories of wood suppliers and would yield the elasticities needed for forecasting the influences of changes in prices and other variables on land use. A second avenue would examine how to model further intensification of timber management by private owners. Private lands that become suddenly unprofitable to manage as forest with a new price structure under $q(T, L)$ might still be best employed in forest under that new price structure if the technology was $q'(T, L)$. Research is needed on the degree of responsiveness by unauthorized cutters to the level and risk of fines for cutting public domain forests. Further research is needed on the values of social, economic, and ecological benefits provided by different kinds of forests and changes in the Rows of these benefits when the forest is lost. More precise measures of these flows would enable more accurate estimates of the welfare and environmental effects of timber price changes, possibly providing societies with enough information to make informed choices on the best policies for attaining the optimal land allocation envisioned by economists and others.

Notes

1. While this treatment implies an even-aged management and forest structure, this may not be the only profitable means of obtaining a timber output. Optimal land use decisions could even start from a condition of standing forests, wherein the optimal harvest decision is affected by the current stand state. But the decision set is only slightly different from that involved in the standard approach (see Strang 1983).
2. If public land that is deforested is eventually converted to private land, then $\partial F_{\mathrm{pr},t+T}/\partial P = -F_{\mathrm{pub},t}\partial\beta^*/\partial P + \partial\gamma/\partial P[\beta^* F_{\mathrm{pub},t} + H_t] + \gamma F_{\mathrm{pub},t}\partial\beta^*/\partial P > 0$ by (8) and by (13), implying that (17) remains ambiguous.

3. As we shall see, NAFTA will lead to depressed timber prices in Mexico, so that the forested portion of Mexico's *ejido* lands should be less threatened, *ceteris paribus,* and that no new incentives for *ejido*-controlled tree plantations or new secondary forests will be created.
4. The increased demand for environmental amenities by the Mexican public at large as a result of the welfare gains from trade presumably occurring from NAFTA are not modeled in this paper. If there are increases in demands for environmental amenities in Mexico because of NAFTA, then the long-run amount of forest cover in Mexico will be larger than implied by the results of my simulations. Further, the amount of welfare change in Mexico caused by NAFTA will probably be small (single-digit percentage increases), so that the size of any increase in demand for environmental amenities would also be small.
5. Unless we believe that the large drop in the peso relative to the dollar in 1995, shortly after NAFTA, was caused by NAFTA, or unless we believe that the drop in the peso caused a structural change in Mexico's economy (i.e., a change in technologies and non-homothetic shifts in preferences), then these studies remain valid as counter-factual analyses.

Appendix: Timber Supply

1. Private Timber Supply

Combining the first-order conditions, (2) and (4), the optimal timber output and the optimal stand harvest age are expressed as a function of prices and land characteristics. As Hartman (1976) and Nautiyal and Williams (1990) implied, the effect of timber price on optimal output and optimal rotation lengths is dependent on the growth function and the interaction of the growth function with inputs. Hence, the effect of timber price on output from a given forestland area is ambiguous:

$$q^* = q^*(P, w, r; U), \frac{\partial q}{\partial P} \leq\geq 0 \tag{A1}$$

and

$$T^* = T^*(P, w, r; U), \frac{\partial T^*}{\partial P} \leq\geq 0 \tag{A2}$$

so that a change in price will have ambiguous effects on average annual harvest quantities from that given forestland area:

$$\frac{\partial \frac{q^*}{T^*}}{\partial P} \leq\geq 0. \tag{A3}$$

Equation (8) in the text referred to the total area of private forestland in a country, expressed as a function of H and γ:

$$F_{\text{pr}} = H \cdot \gamma(P, A, r, w; U). \tag{8}$$

And as implied by Hyde (1980), the derivative of F_{pr} with respect to the forest product price, is positive: $\partial F_{\text{pr}}/\partial P = H\partial\gamma/\partial P > 0$, since H > 0 and $\partial\gamma/\partial P > 0$. Similarly, $\partial F_{\text{pr}}/\partial A = H\partial \gamma/\partial A < 0$. These ideas are embodied in the following specification of short-run private timber supply. This supply is a function not only of the current inventory of standing private timber, but in the case of a permanent (i.e., once and for all) price decrease, also of the change in inventory. The change in inventory will be limited by the proportion of the change (z) that can occur within the year:

$$
\begin{aligned}
S_{\mathrm{pr},t} &= H \cdot \gamma_t \cdot \frac{q^*}{T^*} - [\gamma_t - \gamma_{t-1}] \cdot H \cdot q^{**} \cdot z_t \\
&\qquad \text{if } \gamma_t - \gamma_{t-1} < 0, \\
S_{\mathrm{pr},t} &= H \cdot \gamma_t \cdot \frac{q^*}{T^*} \\
&\qquad \text{if } \gamma_t - \gamma_{t-1} \geq 0
\end{aligned}
\tag{A4}
$$

where q^{**} is the volume of timber per unit area under the previous permanent timber price, other variables are as previously defined, and remembering that $\gamma_t - \gamma_{t-1} > 0$ implies that $\partial P < 0$, and $\gamma_t - \gamma_{t-1} < 0$ implies that $\partial P \geq 0$. In the long-run, say T^* years into the future (because T^* is the expected life of the youngest stands), private supply is simpler because all adjustments from any price change have been made to inventory:

$$S_{\mathrm{pr},t} = H \cdot \gamma_{t+T} \cdot \frac{q^*}{T^*}. \tag{A5}$$

Finally, we note that because a change in price affects q^*, T^*, and L^* in ways dependent on the structure of the timber growth function, $q(T, L)$, unless this function is known, the effect of a permanent price change on total quantity supplied to the market from private lands is ambiguous in both the short- and long-run. However, it seems reasonable to suppose that if the price of timber increases relative to all other goods in the economy, then, as shown in Figure 1, the area of land devoted to forestry will increase, so that there will be a long-run production increase if $\partial q^*/\partial P \leq 0$ or if $\partial P < 0$ but $\partial y/\partial P$ dominates. The converse would also appear to be true.

2. Public Timber Supply

In year t, the unauthorized supply of timber from public forests, $S_{u,t}$, is

$$S_{u,t} = F_{\mathrm{pub},t}\, \beta_t \cdot \tilde{q} \tag{A6}$$

where $\tilde{q}$ is the volume per acre of public forest. Authorized public supply in year t, $S_{a,t}$, is a function of regulated forest area, volume per unit area, and the rotation length, $\tilde{T}$, however determined:

$$S_{a,t} = F_{\mathrm{pub},t} \cdot (1 - \beta_t) \frac{\tilde{q}}{\tilde{T}}. \tag{A7}$$

Authorized supply will decline from one year to the next, as long as there is threatened forest remaining. In year $t + T$, however, the quantity supplied from unauthorized cutters is zero, because all profitably-cut stands are cut in the interim – none of the remaining unregulated government stands provides sufficient benefits when cut to justify cutting. If any public forest remains in T years, public authorized supply is:

$$S_{a,t+T} = F_{\mathrm{pub},t} \cdot [1 - \beta^*(P, A, w, \delta, M; U)] \cdot \frac{q}{\tilde{T}}. \tag{A8}$$

3. Total Timber Supply

Total timber supply proceeds similarly to forest cover. There are different long- and short-run effects, and these differences are due to a slow change in the amount of timber-producing forests on private lands and to the deforestation occurring at the hands of unauthorized cutters. Supply in year t is defined here as the sum of timber supplied to the market from all sources (private, public-authorized, and public-unauthorized):

$$\begin{aligned}
S_t &= S_{\mathrm{pr},t} + S_{a,t} + S_{u,t} \\
S_t &= H \cdot \gamma_t \cdot \frac{q^*}{T^*} - (\gamma_t - \gamma_{t-1}) \cdot H \cdot q^{**} \cdot z_t + F_{\mathrm{pub},t} \cdot (1-\beta_t) \cdot \frac{\tilde{q}}{\tilde{T}} + F_{\mathrm{pub},t} \cdot \beta_t \cdot \tilde{q} \\
&\quad \text{if } \gamma_t - \gamma_{t-1} < 0, \\
S_t &= H \cdot \gamma_t \frac{q^*}{T^*} + F_{\mathrm{pub},t} \cdot (1-\beta_t) \cdot \frac{\tilde{q}}{\tilde{T}} + F_{\mathrm{pub},t} \cdot \beta_t \cdot \tilde{q} \\
&\quad \text{if } \gamma_t - \gamma_{t-1} \geq 0,
\end{aligned} \tag{A9}$$

The effect of a price change in year ton total stumpage supply in year t depends on the sign of $(\gamma_t - \gamma_{t-1})$. If it is negative, meaning that private forest area contracts, then

$$\frac{\partial S_t}{\partial P_t} = F_{\mathrm{pub},t} \cdot \tilde{q} \left[-\frac{1}{\tilde{T}} \cdot \frac{\partial \beta_t}{\partial P_t} + \frac{\partial \beta_t}{\partial P_t} \right] + H \cdot \gamma_t \cdot \left[\frac{q^*}{T^*} - \frac{q^{**}}{T^{**}} \right] + H \cdot z_t \cdot q^* \cdot \frac{\partial \gamma_t}{\partial P_t}. \tag{A10}$$

If it is positive, meaning that private forest area expands, then

$$\frac{\partial S_t}{\partial P_t} = F_{\mathrm{pub},t} \cdot \tilde{q} \left[-\frac{1}{\tilde{T}} \cdot \frac{\partial \beta_t}{\partial P_t} + \frac{\partial \beta_t}{\partial P_t} \right] + H \cdot \gamma_t \cdot \left[\frac{q^*}{T^*} - \frac{q^{**}}{T^{**}} \right]. \tag{A11}$$

Note that in (A 10) and (A I 1), the short-run supply response from private lands includes the adjustment in timber volumes harvested per year caused by the change from the previous optimal quantity and rotation to the new optimal quantity and rotation.

The derivative of β with respect to timber price is positive, $F_{\mathrm{pub},t}$ and $\tilde{q}$ are positive, and $\tilde{T}$ is greater than one. But because the quantity shown in the second set of brackets in (A10) is of indeterminate sign, the short-run total response to a price decrease is ambiguous. Similar reasoning leads us to the finding that (Al 1) cannot be signed, either.

Long-run supply is the sum of private production and public production. Assuming that all unauthorized cutting will be completed after T years:

$$\begin{aligned}
S_{t+R} &= S_{\mathrm{pr},t+R} + S_{a,t+R} \\
S_{t+R} &= H \cdot \gamma_{t+R} \cdot \frac{q^*}{T^*} + F_{\mathrm{pub},t} \cdot (1-\beta^*) \cdot \frac{\tilde{q}}{\tilde{T}}.
\end{aligned} \tag{A12}$$

A price change in year t will alter long-run production as follows:

$$\frac{\partial S_{t+T}}{\partial P_t} = h \cdot \frac{q^*}{T^*} \cdot \frac{\partial \gamma_{t+T}}{\partial P_t} - F_{\mathrm{pub},t} \cdot \frac{\tilde{q}}{\tilde{T}} \frac{\partial \beta^*}{\partial P_t}. \tag{A13}$$

The first derivative on the right-hand-side, the partial effect of a price change on private output, as discussed earlier, is probably positive. The' last term is also positive. But the minus sign between these two terms renders the long-run effect of the price change indeterminate. The indeterminate nature of (A13) is interesting, because it implies that only an empirical analysis of a particular country's situation will reveal the effects of price changes on supply. It cannot be assumed that supply will increase with a timber price increase.

References

Anderson, L. E. and E. J. Reis (1997), 'Deforestation, Development, and Government Policy in the Brazilian Amazon: an Econometric Analysis', *Texto Para Discussão* No. *513.* Rio de Janeiro, Brazil: Instituto de Pesquisa Econômica Aplicada.

Bachrach, C. and L. Mizrahi (1992), 'The Economic Impact of a Free Trade Agreement Between the United States and Mexico: a CCE Analysis,' in J. F. Francois, C. R. Shiells, M. M. Arce, K. Johnson, K. A. Reinert and S. P. Tokarick, eds., *Economy-wide Modeling of the Economic Implications of a FTA with Mexico and a NAFTA with Canada and Mexico (Addendum to the Report on Investigation No. 332-317, under Section $32 of the Tariff Act* of *1930)*, Publication 2508. Washington, DC: United States International Trade Commission.

Barbier, E. B.. N. Bockstael. J. C. Burgess and I. Strand (1995a), 'The Linkages Between the Timber Trade and Tropical Deforestation – Indonesia', *The World Economy* **18**, 411-442.

Barbier, E. B., J. C. Burgess, J. Bishop and B. Aylward (1995b), *The Economics of the Tropical Timber Trade.* London, U.K.: Earthscan.

Barbier, E. B. and J. C. Burgess (1996), 'Economic Analysis of Deforestation in Mexico', *Environment and Development Economics* **1,** 203–239.

Barbier, E. B. and J. C. Burgess (1997), 'The Economics of Tropical Forest Land use Options', *Land Economics 73, 174-195.*

Brown, D. K., A. V. Deardorff and R. M. Stern (1992). 'A North American Free Trade Agreement: Analytical Issues and a Computational Assessment', *The World Economy* **15, 11-29.**

Comolli, P. M. (1981), 'Principles and Policy in Forestry Economics', *Bell Journal of Economics* **12,** 300–309.

Deacon, R. T. (1994), 'Deforestation and the Rule of Law in a Cross-section of Countries', *Land Economics 70, 4* 14–430.

Deacon, R. T. (1995), 'Assessing the Relationship Between Government Policy and Deforestation', *Journal of Environmental Economics and Management 28,* I-18.

Diario Official (1997). 'Decreto por el que se Reforma la Ley Forestal', Diario Oficial, Martes, 20 Mayo.

FAO (1997), 'FAO Stat Database', <http://apps.fao.org/lim500/Agri_db.pl>.

Faustmann, M. (1849), 'On the Determination of the Value Which Forest Land and Immature Stands Possess for Forestry,' in M. Gane. ed. *Institute paper* 42 (1968), Oxford: Commonwealth Forestry Institute, Oxford University.

Ford, L. B. (1999), 'Policies Affecting the Adoption of Agroforestry Systems in the States of Campeche and Quintana Roo, Mexico', Paper to be presented at the 6th North American Agroforestry Conference, Hotsprings, Arkansas, June 12-16, 1999.

Hardie, I. W. and P. J. Parks (1997), 'Land Use with Heterogeneous Land Quality: an Application of an Area Base Model', *American Journal of Agricultural Economics 79, 299-3* 10.

Hartman, R. (1976), 'The Harvesting Decision When a Standing Forest Has Value'. *Economic Inquiry* **14,** 52–58.

Hufbauer, G. C. and J. J. Schott (1992), *North American Free Trade: Issues and Recommendations,* Washington, D.C.: Institute for International Economics.

Hyde, W. F. (1980), *Timber Supply, Land Allocation, and Economic Efficiency*, Baltimore, M.D.: Johns Hopkins Press.

Knetsch, J. L. (1993), 'Resource Economics: Persistent Conventions and Contrary Evidence,' in W. L. Adamowicz, W. White, and W. E. Phillips, eds., *Forestry and the Environment: Economic Perspectives,* Wallingford, U.K.: C.A.B. International.

Kravis, I. B.. A. Heston and R. Summers *(1982). World Product and Income; International Comparisons of Real Gross Product,* Baltimore, M.D.: Johns Hopkins University Press and the World Bank.

Nelson, G. C. and D. Hellerstein (1997), 'Do Roads Cause Deforestation'? Using Satellite Images in Econometric Analysis of Land *Use', American Journal of Agricultural Economics 79, 80-88.*

Nautiyal. J. C. and J. S. Williams (1990), 'Response of Optimal Stand Rotation and Management Intensity to One-Time Changes in Stumpage Price, Management Cost, and Discount Rate', *Forest Science 36. 2* 12–223.

Parks, P. J. and B. C. Murray (1994), 'Land Attributes and Land Allocation: Nonindustrial Forest Use in the Pacific Northwest', *Forest Science 40,* 558–575.

Plantinga, A. J. (1996), 'The Effect of Agricultural Policies on Land Use and Environmental Quality', *American Journal **of** Agricultural Economics 78, 1082-109* 1.

Prestemon, J. P. and J. Buongiorno (1996), 'The Impacts of NAFTA on U.S. and Canadian Forest Product Exports to Mexico', *Canadian Journal **of** Forest Research 26,* 794–809.

Primo Braga, C. A. (1992), 'Tropical Forests and Trade Policy: the Cases of Indonesia and Brazil,' in D. Adams, R. Haynes, B. Lippke and J. Perez-Garcia, eds., *Forest Sector, Trade, and Environmental Impact Models: Theory and Applications,* Seattle: Center for International Trade in Forest Products, University of Washington.

Procuraduria Agraria (1995), Legislación Agraria. Distrito Federal, Mexico.

Reis, E. and R. Guzman (1994), 'An Econometric Model of Amazon Deforestation', in K. Brown and D. W. Pearce, eds., *The Causes of Tropical Deforestation*, Vancouver, B.C., Canada: UBC Press.

Roland-Holst, D., K. A. Reinert and C. R. Shiells (1992), 'North American Trade Liberalization and the Role of Nontariff Barriers'. in J. F. Francois, C. R. Shiells, M. M. Arce, K. Johnson, K. A. Reinert and S. P. Tokarick, eds.. *Economy-wide Modeling of the Economic Implications **of** a FTA with Mexico and a NAFTA with Mexico and a NAFTA with Canada and Mexico (Addendum to the Report on Investigation No. 332-317, under Section 332 **of** the Tariff Act **of** 1930)*, Washington, D.C.: United States International Trade Commission.

Samuelson, P. A. (1976), 'Economics of Forestry in an Evolving Society', *Economic Inquiry* **14,** 466-492.

Segura, G. (1998), 'The State of Mexico's Forest Resources Management and Conservation', Internet manuscript (http://wwww.semarnap.gob.mx/ssrn/conaf/statfor.htm#state), published July 29, 1998. Mexico City, Mexico: Centro de Ecología, Universidad Nacional Autónoma de Mexico.

SARH *(1993). Ley Forestal.* Distrito Federal, Mexico: Secretaria de Agricultura y Recursos Hidraulicos.

SEMARNAP (1996), *Programa Forestal y de Suelo:* 1995-2000. Distrito Federal, Mexico: Secretaría de Medio Ambiente, Recursos Naturales y Pesca.

Southgate, D. (1990), 'The Causes of Land Degradation along 'Spontaneously' 'Expanding Agricultural Frontiers in he Third World', *Land Economics 66, 93-101.*

Strang, W. J. (1983), 'On the Optimal Forest Harvesting Decision', *Economic Inquiry 21,* 576–583.

Swanson, T. M. (1994), 'The Economics of Extinction Revisited and Revised: A Generalized Framework for the Analysis of the Problems of Endangered Species and Biodiviersity Loss', *Oxford Economic Papers* **46**, 800–82 1.

Tomberlin, D., J. Buongiorno and D. Brooks (1998), 'Trade, Forestry and the Environment: A Review', *Journal of Forest Economics 4, 177-206.*

Vincent, J. R. (1990), 'Don't Boycott Tropical Timber,' *Journal of Forestry* **8**, 56.

Vincent, J. R. (1992), 'The Tropical Timber Trade and Sustainable Development', *Science* 56, 165 1–1655.