CIDE

NÚMERO 172

Juan Manuel Torres y Ramiro Flores

DEFORESTATION AND CHANGE OF LAND USE IN MEXICO

Resumen

Este documento discute el problema de estimar la cubierta forestal de estado estacionario bajo diferentes escenarios de producción y diferentes condiciones de mercado. El modelo se basa en el modelo desarrollado por Ehui *et al.* (1990), el cual es adaptado para incluir los sectores agrícola y ganadero. El modelo es un modelo de control óptimo que supone la existencia de un agente planeador central que desea maximizar los productos derivados de la agricultura, ganadería y silvicultura sujeto a restricciones de extensión de suelo y dinámicas de cambios de suelo usado para diferentes propósitos. El modelo asume que la deforestación se debe enteramente a cambios en el uso del suelo de propósitos silvícolas a propósitos agrícolas y ganaderos. En suma, el cambio de suelo dedicado a agricultura para dedicarlo a ganadería y viceversa no tiene efecto en la cubierta forestal. Se presenta una aplicación empírica que usa datos de corte transversal y recursos e información de mercado a nivel estatal. Los resultados muestran que el stock forestal actual puede mantenerse a tasas de interés entre el 3.5 y 4%. Tasas de interés más altas inducen a la deforestación principalmente por actividades ganaderas. Finalmente, los incrementos en valor por las actividades forestales tiene efectos fácilmente perceptibles en mitigar la deforestación.

Abstract

This paper addresses the problem of estimating the steady state forest cover in Mexico under different scenarios of production and market conditions. The model is based on the model developed by Ehui *et al.* (1990), which is adapted to include agriculture and stockbreeding sectors. The model is an optimal control model which assumes a central planning agent who wishes to maximize yields coming from agriculture, livestock and forestry subject to land constraints and dynamics of shifts on land used to different purposes. The model assumes that deforestation is entirely due to changes in land use from forestry to agricultural and stockbreeding purposes. In addition, shifts from land devoted to agriculture to livestock and vice versa do not have any effect on forest cover. An empirical application is presented, which uses cross sectional data and resources and market information at State level. Results show that current forest stock can be maintained at interest rates ranging from 3.5 to 4%. Higher interest rates induce deforestation mainly from stockbreeding activities. Finally, increments in value for forest activities have conspicuous effects on mitigating deforestation.

Keywords: Deforestation, Dynamic Models, Steady State Forest Stock.

1. *Introduction*

Approximately 26 percent of Mexico's 191 million hectare (ha) land area (49.7 million ha) is covered with closed forests, most of them temperate forests. However, the country suffers from heavy deforestation problems, especially in the tropics. Some estimates indicate that tropical evergreen forests presently constitute only an estimated 10 percent of their original coverage (Rzedowski, 1978), and that the whole forest cover is only half the area covered by forests 35 years ago. The problem is that serious that even the 1992 forest global assessment ranked the country in first place given the annual rate of deforestation (1.3 percent) and fourth according to the deforested area (FAO, 1993).

In recent years, deforestation has become a crucial issue in the environmental management agenda for the country. This change of attitudes is due to the society's recognition about the role of forest areas for the production of several goods and environmental services. In addition, environmental problems such as "El Niño", "La Niña" and global warming, as well as the environmentalist movements (mainly acting on Education, Health and Tourism among others) have forced such a change on the society's perspective. This growing interest on the deforestation problem has forced the most recent change of forest legislation in the country, as well as the increment of budget tied to reforestation, forest health, protection, and sustainable forest management activities.

The most recent forest legislation provides the framework to improve forest activities in a more holistic concept. It considers not only timber production, but also all goods and services produced from forests, as well as the important role of forest communities on forest conservation. This means that logging activities are more constrained and more care is given to conservation and integrated sustainable management practices that consider multiple ecological and socioeconomic factors.

In spite of this new framework, the deforestation process is still taking place and Government actions do not yield the expected results. Commercial harvesting, forest fires and pests contribute to deforest some areas, mainly in the southeast of the country. However, the main cause of deforestation, particularly in the tropics and heavy populated areas, is the conversion of forestlands to agricultural and stockbreeding activities. Expansion of the agricultural frontier and cattle ranching is by far the leading factor in the clearing of forests in Mexico (Toledo, 1990).

Based upon this framework, this paper attempts to estimate deforestation and predict future forest stock conditions based on the assumption that most of the deforestation is due changes of land use. There is a vast literature related to deforestation, most of it showing causes (Allen and Barnes, 1985), economic problems (Barbier *et al.*, 1991) and policy implications of the process (Dotzauer, 1993). However, much of the economic literature on deforestation is based on econometric models, which stress different factors as causes of deforestation. These factors depend upon the scope of the model. Thus, there are macro-models which explain the process of deforestation for different nations (Vesterby y Heimlich, 1991; Barbier *et al.*, 1993; Deacon, 1994). Within this type of models the factors most commonly used to explain deforestation have been population growth, economic development, trade and government policies (Binswanger, 1991). On the other extreme, there exist models which explain deforestation for a particular country or region based on specific factors causing deforestation (Brown and Lugo, 1992; Oyama *et al.*, 1993; Brown and Pearce, 1994). These models refer to variables such as change of land use, technological change, road construction and the market of forest products among others.

The model referred in this paper is an application of the model initially developed by Vousden (1973) and extended by Ehui *et al.* (1990). Additional applications of this model can be found in Ehui and Hertel. (1989), and Adamson (1997). The model is an optimal control model, which relies on the estimation of an aggregate production function for the agricultural sector to estimate the desirability of maintaining the forest or clearing the land in a given period. In this paper, the original model is adapted to use cross section data and to include the stockbreeding sector. The paper is organized as follows. The next section shows the basic assumption, the model extension and the main steady state results. The third section presents the results derived from the econometric work and the scenario simulations. Finally, the last section shows some concluding remarks.

2. *Model*

The original model presents the problem of a central planning agent who attempts to maximize the present value of the utility (social welfare) derived from aggregate profits obtained from the forestry and agriculture sectors (Vousden, 1973). Such a model is adapted to include a third sector, the stockbreeding sector and the same framework.

2.1. Model specification

The model objective functional is defined as the maximization of the present value of the utility derived from producing in the forestry, agriculture and stockbreeding sectors. The model constraints are defined as changes in forest stock over time and the relationship between yields obtained from different sectors. A fundamental assumption of this model is that forestland can have one additional use that could be agriculture or livestock production, but not both additional uses. In other words, there is an initial endowment of forestland, which can have either of the two sets of uses: agriculture and forestry or forestry and stockbreeding, but not agriculture, forestry and stockbreeding. Indeed, this last possibility of potential land use is feasible, however forestland is converted to just one of the two additional uses. In the long run, this possibility establishes shifts in land use from agriculture to

stockbreeding and *viceversa*. Such shifts, although possible, are just part of the land accounts and do not affect forest cover.
Formally, the control problem is stated as:

$$\underset{D_A, D_L, X_A, X_L}{Max} \quad U = \int_0^{\infty} \left[W\left(\Pi\left(D_A, D_L, X_A, X_L, F\right)\right)\right] e^{-rt} dt \qquad (1)$$

subject to

$$\begin{aligned} &\dot{F}_A = -D_A(t) \\ &\dot{F}_L = -D_L(t) \\ &F_A(t), F_L(t), D_A(t), D_L(t), X_A(t), X_L(t) \geq 0 \\ &F_A(0) + F_L(0) = F(0) = L_A + L_L = given \\ &D_A(t) + D_L(t) = D(t) \end{aligned} \qquad (2)$$

$$\Pi(\cdot) = P_F(t)\, F(t) + \left[L_A - F_A(t)\right]\left\{P_A(t)\, Z\left[D_A(t), F_A(0) - F_A(t), X_A(t), PP(t)\right] - P_{XA}\, X_A(t)\right\} + \left[L_L - F_L(t)\right]\left\{P_L(t)\, Y\left[D_L(t), F_L(0) - F_L(t), X_L(t)\right] - P_{XL}\, X_L(t)\right\} \qquad (3)$$

Where U represents the present value of society's welfare, r is the social rate of discount; $W(.)$ is a twice differentiable welfare function which depends upon aggregate profit Π. The profit function (3) is the sum of net returns obtained from forestry, agriculture and stockbreeding; L_A represents the total land area suitable for agricultural use, while L_L is the total land suitable for livestock production. $F(t)$ represents the total land area covered by forests at time t, while $F_A(t)$ is the land area currently covered by forests that can be used for agricultural purposes in contrast to $F_L(t)$, that represents the forested area that might be used for livestock production. It is assumed that the forestland can be used either for agricultural or livestock production, and there is some forestland that can be used exclusively for forestry.

$Z(\cdot)$ is a concave yield function for the agricultural sector, while $Y(\cdot)$ represents the (concave) yield function for the stockbreeding sector. Both production functions depend upon the purchased inputs ($X_A(t)$ for the agricultural sector, and $X_L(t)$ for the stockbreeding sector). $D(t)$ represents the total rate of deforestation, which can be due to the agricultural sector ($D_A(t)$) or to the livestock sector($D_L(t)$). The difference [$F_i(0) - F_i(t)$] shows the cumulative amount of deforested land to be incorporated to the *i-th* sector, while $PP(t)$ represents annual precipitation at time t. Variables $P_A(t)$ and $P_L(t)$ denote prices per unit (*e.g.* Kg, Tn) returns to agriculture and stockbreeding at time t. $P_F(t)$ denotes per hectare returns to forestry at time t. Following the same nomenclature, $P_{XA}(t)$ denotes per unit agricultural input prices, while $P_{XL}(t)$ indicates per unit prices for inputs used in livestock production.

2.2. Model assumptions

The formulation presented above has the following characteristics and assumptions:

i) The total forestland can be used either for agricultural or stockbreeding production. However, the forestland incorporated into the agricultural sector can not be incorporated also into the livestock production after it has been cleared. Shifts of land between the agricultural and stockbreeding sectors might exist and the model does not account for such changes. This assumption is somehow restrictive in the short run, however in the long run land should be allocated to its most profitable use. The experience in Mexico shows that it is very unlikely that land might be incorporated to the forestry sector in the future once is cleared (SARH, 1990), unless some land conversion or land rehabilitation governmental program is conducted. For this reason, this assumption does not affect the main purpose of the model, namely, to evaluate deforestation.

ii) Social welfare increases as profit increases and there exist diminishing marginal utilities from additional profits. Formally, this assumption implies:

$$\partial W[\Pi]/\partial \Pi \geq 0$$

$$W_{\Pi\Pi} \leq 0$$

iii) Agricultural yields increase as deforestation increases but at a decreasing rate. This effect is attributable to the nutrient content of the ashes left after burning, especially in tropical forests (Sánchez, 1976; Hernández *et al.*, 1987; Ehui, *et al.* 1990; Levy *et al.* 1991). Such ashes suffer a fast degradation process, leaving soils with a low nutrient content. In the case of temperate forests, a similar effect can be attributable to bare land erosion and lack of soil conservation practices after clearing or burning (Sánchez and Ortiz ,1991). This assumption implies:

$$\partial Z/\partial D_A(t) > 0$$

$$\partial^2 Z/\partial D^2{}_A(t) < 0$$

$$\partial Z/\partial [F_A(0) - F_A(t)] < 0$$

Observe that the third inequality assumes that for a given period t, as more marginal lands (lands currently covered by forests) are incorporated into the arable land base, lower agricultural yields are obtained. This assumption is consistent with the fact that current forestlands are located on steep terrain, high altitudes and with poor access infrastructure.

iv) Forestlands incorporated to stockbreeding production are only used for cattle raising. It is assumed that this activity only affects the stock of goats, sheep and bovine cattle, which are used exclusively for meat production. In addition, it is assumed that increments on deforestation increase meat production but at decreasing rates, because of increases in costs associated with ranching more distant areas as well as costs associated with crowding (Aguirre, 1996). This assumption formally implies:

$$\partial Y / \partial D_L(t) > 0$$

$$\partial^2 Y / \partial D^2{}_L(t) < 0$$

$$\partial Y / \partial \left[F_L(0) - F_L(t)\right] < 0$$

Observe also that the last inequality indicates that the use of forestlands for grazing leads to lower meat yields, implying that the forestland is a marginal land for livestock production; assumption that might not hold in some cases.

v) Agricultural and meat yields increase as inputs increase but at diminishing marginal yields. This assumption results from the basic idea of diminishing marginal yields from any resource, assumption also valid for both biological production systems: agriculture and stockbreeding. The assumption just implies:

$$\partial Y / \partial X_L(t) > 0 \qquad \partial Z / \partial X_A(t) > 0$$

$$\partial^2 Y / \partial^2 X_L(t) < 0 \qquad \partial^2 Z / \partial^2 X_A(t) < 0$$

vi) The following second order derivatives are supposed equal zero to easy some of the results:

$$\partial^2 Y / \partial^2 F_L(t) = 0 \qquad \partial^2 Y / \partial F_L(t) \partial X_L(t) = 0$$

$$\partial^2 Z / \partial^2 F_A(t) = 0 \qquad \partial^2 Z / \partial F_A(t) \partial X_A(t) = 0$$

2.3. Steady state solution

The current value Hamiltonian associated with model describe by (1) - (3) is given by:

$$\tilde{H} = W\left(\Pi\left(D_A,\ D_L,\ X_A,\ X_L,\ F\right)\right) - \lambda D_A(t) - \mu D_L(t) \qquad (4)$$

Where λ and μ denote current value costate variables associated with the equations of motion defined in (2). Assuming the existence of an interior solution, the maximum principle requires the following conditions to hold:

Optimality conditions:

$$\tilde{H}_{XA} = W_{\Pi}\left[\left(L_A - F_A(t)\right)\left(P_A\ Z_{XA} - P_{XA}\right)\right] = 0 \quad (5)$$

$$\tilde{H}_{XL} = W_{\Pi}\left[\left(L_L - F_L(t)\right)\left(P_L\ Z_{XL} - P_{XL}\right)\right] = 0 \quad (6)$$

$$\tilde{H}_{DA} = W_{\Pi}\left[\left(L_A - F_A(t)\right)\left(P_A\ Z_{DA} - P_{XA}\right)\right] = \lambda \quad (7)$$

$$\tilde{H}_{DL} = W_{\Pi}\left[\left(L_L - F_L(t)\right)\left(P_L\ Y_D - P_{XL}\right)\right] = \mu \quad (8)$$

Costate equations:

$$-\tilde{H}_{FA} = \dot{\lambda} - r\lambda = W_{\Pi}\left[P_F + \left(L_A - F_A(t)\right)\left(P_A\ Z_{FA}\right) - \left(P_A\ Z\right) + \left(P_A\ X_A\right)\right] \quad (9)$$

$$-\tilde{H}_{FL} = \dot{\mu} - r\mu = W_{\Pi}\left[P_L + \left(L_L - F_L(t)\right)\left(P_L Y_{FL}\right) - \left(P_L\ Y\right) + \left(P_L\ X_L\right)\right] \quad (10)$$

and transversality conditions given by:

$$\lim_{t \to \infty} e^{-rt}\lambda(t)F_A(t) = 0 \quad (11)$$

$$\lim_{t \to \infty} e^{-rt}\mu(t)F_L(t) = 0 \quad (12)$$

Conditions (5) - (10) have the same interpretation as the one given by Ehui and Hertel (1989). Conditions (5) and (6) imply that at the optimum the purchased inputs have to be applied at the level where marginal utilities are zero. Equation (7) indicates that at any point in time, the rate of deforestation coming from the agriculture sector should be chosen so that the marginal utility of deforestation equals the opportunity cost of the forest stock (λ). Condition (8) has an analogous interpretation as equation (7) but for the stockbreeding sector. Conditions (9) and (10) imply that forest stock should be employed to the point where marginal utility of forest capital is equal to the social cost of such a capital. Observe that in these conditions the right hand side of equations (9) and (10) integrate both: the marginal contribution of forestry $\left(W_{\Pi} P_F\right)$ and the indirect marginal contribution of the forestland to agricultural and stockbreeding productivity.

Under steady state conditions, the change on forest stock should be zero, which means that:

$$\dot{F}(t) = \dot{F}_A(t) = \dot{F}_L(t) = D_A(t) = D_L(t) = D(t) = 0 \quad (13)$$

By using this assumption and equations (5) - (8) the steady state forest stock can be defined by:

$$\frac{1}{r}W_{FA}\left(D_A, F_A, X_L, X_A\right) = W_{DA}\left(D_A, F_A, X_L, X_A\right) \quad (14)$$

$$\frac{1}{r}W_{FL}\left(D_L, F_L, X_L, X_A\right) = W_{DL}\left(D_L, F_L, X_L, X_A\right) \quad (15)$$

$$Z_{XA}\left(D_A, F_A, X_A\right) = {P_{XA}}/{P_A} \quad (16)$$

$$Y_{XL}\left(D_L, F_L, X_L\right) = {}^{P_{XL}}\!/_{P_L} \tag{17}$$

Since by assumption (i) there is no land that can be potentially used for agriculture, forestry or stockbreeding, then first order conditions for agriculture (5 and 7) are totally independent from the ones for stockbreeding (6 and 8). Therefore, conditions (14 – 17) are basically an extension of those developed by Ehui *et al* (1990). Condition (14) states that in steady state, the marginal utility of deforestation made on forest lands with likely agricultural use (W_{DA}) must equal the present value of the forgone marginal future benefit of those lands $\left({}^{1}\!/_{r} W_{FA}\right)$. Condition (15) just indicates the same argument for those forestlands with likely use for livestock production. Ehui *et al.* (1990) called (W_{DA}) the preference for deforestation (in this case due to change of land use for agriculture purposes) and considered (W_{FA}) the conservation motive. Such a terminology is also valid for this model extension given separate sources of deforestation. Equations (16) and (17) just show the basic equilibrium condition in production theory: Value Marginal Product equals marginal cost for both aggregate products (See Ehui *et al.*, 1990, for a detailed discussion on these conditions and the associated phase diagrams).

2.4. Specification of yield functions

The basic idea of the yield functions is to estimate an aggregate yield for both sectors, namely agricultural sector ($Z(t)$) and the stockbreeding ($Y(t)$) sector. Because second order derivatives of yield functions for some parameters are critical to the analysis, the second order approximation developed by Ehui and Hertel (1989) was adopted with few changes. The quadratic functional form adopted for the agricultural production function was:

$$\begin{aligned} Z(t) &= \alpha_0 + \alpha_1[X_A(t)] + \alpha_2[D_A(t)] + \alpha_3[F_A(0) - F_A(t)] + \alpha_4[AT(t)] + \\ &+ \tfrac{1}{2}\alpha_{11}[X_A(t)]^2 + \tfrac{1}{2}\alpha_{22}[D_A(t)]^2 + \alpha_{12}[D_A(t)X_A(t)] \end{aligned} \tag{18}$$

Where the term $AT(t)$ denotes technological change in the agricultural sector. The functional form adopted for the livestock production sector was:

$$\begin{aligned} Y(t) &= \beta_0 + \beta_1[X_L(t)] + \beta_2[D_L(t)] + \beta_3[F_L(0) - F_L(t)] + \beta_4[LT(t)] + \beta_5[PP(t)] + \beta_6[D_Y] + \\ &+ \tfrac{1}{2}\beta_{11}[X_L(t)]^2 + \tfrac{1}{2}\beta_{22}[D_L(t)]^2 + \beta_{12}[D_L(t)X_L(t)] \end{aligned} \tag{19}$$

For this model the term $LT(t)$ denotes de technological change in the stockbreeding sector at time t. The term $PP(t)$ represents the precipitation at time t and D_Y is a dummy variable to account for different time periods in the intercept. AT is measured in terms of machinery per unit of arable land, while LT is measured by the litters of milk produced, since this production reflects a proxy of the stabled stock.

As can be observed, both equations are not complete second order approximations of the functional form, since only important interaction and quadratic terms are considered. The main reason to avoid some terms is the lack of enough information. Only one interaction term is included, *X(t)* and *D(t)* because according to Sanchez (1976, 1981) current period deforestation is analogous to fertilization, whose effect decreases rapidly after some years, hence this term provides a mean to test this statement.

Considering the assumptions about the yield function the following signs are expected for the parameters in both equations: α_0, α_1, α_2, α_4, α_{25}, β_0, β_1, β_2 β_4, β_5 ≥ 0; α_3, α_{11}, α_{22}, α_{12}, β_3, β_{11}, β_{22}, β_{12} ≤ 0.

2.5. Steady state forest cover

By solving equations (14) to (17) the optimal steady state forest stock can be found. The optimal level of inputs X^* can be found by solving equations (16) and (17). For the agricultural sector the resulting levels are:

$$X_A^* = \left(\overline{P}_{XA} - \alpha_1\right) / \alpha_{11}$$

where $\overline{P}_{XA}$ represents the ratio P_{XA}/P_A. Similarly, by defining $\overline{P}_{XL}$ as the ratio P_{XL}/P_L the optimal input level for the stockbreeding sector yields:

$$X_L^* = \left(\overline{P}_{XL} - \beta_1\right) / \beta_{11}$$

By solving equation (14) and considering (13) optimal forest cover with possible agricultural use yields:

$$F_A^* = F_A(0) + \frac{\Delta}{\Omega} + \frac{(\Omega - \alpha_3)A}{\Omega}$$

Where:

$$\Delta = \alpha_0 + \alpha_1 X_A^* + \tfrac{1}{2}\alpha_{11} X_A^* + \alpha_4 AT - \overline{P}_{XA} X_A^* - \overline{P}_{FA} \text{, and}$$

$$\Omega = r\left(\alpha_2 + \alpha_{12} X_A^*\right) + 2\alpha_3$$

Here $\overline{P}_{FA}$ represents the per hectare returns from forestry activities relative to the price of agricultural outputs P_F/P_{XA} and $A = L_A - F_A(0)$. Following the same steps and by using equation (15), the optimal forest cover of forestlands that can also be used for livestock production is:

$$F_L^* = F_L(0) + \frac{\Gamma}{\Phi} + \frac{(\Phi - \beta_3)B}{\Phi}$$

Where:

$$\Gamma = \beta_0 + \beta_1 X_A * + \tfrac{1}{2}\beta_{11} X_A * + \beta_4 LT + \overline{P}_{XL}\ X_L * - \overline{P}_{FL}$$, and
$$\Phi = r(\beta_2 + \beta_{12} X_L *) + 2\beta_3$$

For these equations $\overline{P}_{FL}$ represents the per hectare returns from forestry activities relative to the price of livestock outputs P_F/P_{XL} and $B=L_L - F_L(0)$. Comparative statics results of the model are detailed in Ehui and Hertel (1989) and Ehui *et al.*, (1990).

3. *Empirical Application*

The following application was carried out by using data from Mexico. Given that only three forest inventories have been performed in the country, the main limitation was the availability of forest data. Hence the information was grouped for each one of the states and runs to estimate agricultural and stockbreeding production functions were performed at state level.

3.1. Data base

Forest cover estimates for Mexico depend upon the source of information and the method used to estimate and classify forest vegetation. Cairns *et al.* (1995) have found that different sources of information have different definitions of forest types and degrees of forest degradation. Most of them use different methodologies to sample and estimate forest cover (Castillo *et al.*, 1989; FAO 1990; Masera *et al.*, 1993; SARH, 1986). There is only one source of information that provides the most complete data under a consistent format. This source is the state by state forest inventories conducted in the country by the National Forest Service. The first state level forest inventory was initiated at the beginning of the sixties and finished until the middle of the 80's (SARH, 1986). A second forest inventory was performed in 1990 (SARH, 1992) and the third one was performed in 1994 (SARH, 1994). These three nation wide forest inventories integrate the only information available of forest cover for the whole country.

Given the lack of reliable time series information at national level, a different approach to estimate the production functions was followed. Instead, cross section information at state level was used to fit the models. Thus, the sample consisted of 31 states (the federal capital was not included) and two measures of deforestation; one obtained from the first and second forest inventories and the second one by using the second and third forest inventories. Price information from the forest sector was obtained from the quarterly (and sometimes monthly) economic reports from the National Forest Service. Mexican forest industry outlook reports were also used to gather some additional information.

Aggregate agriculture yields were estimated according to a quantity index for the major food crops produced in marginal lands in Mexico. These crops included:

rice, corn, wheat, barley, beans, potato and sorghum. The quantity index was estimated as the geometric mean of the quantity indexes estimated as:

$$I_{90} = \frac{\sum_j p_{jtk} q_{jtk}}{\max_k \left(\sum_j p_{j90k} q_{j90k} \right)}$$

$$I_{94} = \frac{\sum_j p_{jtk} q_{jtk}}{\max_k \left(\sum_j p_{j94k} q_{j94k} \right)}$$

Where I_{90} and I_{94} are the quantity indexes based on prices indexed to 1990 and 1994 respectively. The values p_{jtk} and q_{jtk} are respectively the price and quantity of the *j-th* commodity, at time t (indexed according to the base year defined by the index, *e.g.* 1990 or 1994) produced in the state k. The production quantity index (I) was then estimated as:

$$I = \sqrt{I_{90} \cdot I_{94}}$$

Agricultural production, market information on products and factors at state level were obtained from the FAO/IMTA (1995) agriculture data base, as well as SARH (1980) and SAGAR (1995) data base. Additional information was obtained from the INEGI's agricultural census and the Ministry of Agriculture bulletins (SARH, 1993). Estimates about potential use of forest lands was obtained from different sources such as SARH, 1993, and SAHOP 1991.

Land devoted to agriculture was used as a proxy for the agricultural inputs. The land was weighted by the corn yield obtained for each one of the states under two classes: irrigated and non irrigated land. Then a new variable expressing the total agricultural land was obtained as:

$$X_A = \frac{y_i * L_i + y_n * L_n}{y_n}$$

Where y represents the corn yield either in irrigated land (subscript i) or in non irrigated land (subscript n) and L is the total amount of land devoted to agricultural production either in irrigated land (subscript i) or in non irrigated land (subscript n).

Aggregate meat yields were also measured (in heads of cattle) through indexes from cow, sheep and goat heads produced in Mexico (at state by state basis). Meat production, number of heads, productivity indexes for forage and price information for the stockbreeding sector were obtained from SARH (1994), SAGAR (1996) and SAGAR (1998).

An estimate of amount of forage obtained from land devoted to grazing was calculated by using the information on forage production and grazing productivity published by COTECOCA (1994) and SAGAR (1998). This total amount of forage at state level was used as a proxy for the input level to estimate the production function (19). Annual precipitation was considered another important input for the production function. It was obtained from the data base published by Quintas (1996)

Returns were defined as follows. Annual per hectare returns in agriculture was defined as the total annual real value of the food crops listed above divided by the area used to produce them. Annual per hectare meat production returns were defined as the total annual real value of the meat produced by the standing heads (cows, sheep, and goats) divided by the number of hectares of grazing. Finally, annual per hectare returns to forestry were defined as the weighted (by volume produced) average annual price of all timber species times their average annual production per unit of land (in cubic meters per hectare). This latter result is obtained by multiplying the density of tradable trees (in cubic meters per hectare) by their annual growth rate.

3.2. Estimated models

Estimates for the yield functions $Z(t)$ and $Y(t)$ were obtained by using Weighted Least Squares estimation. Production indexes were normalized by using a Box-Cox power transformation. Resulting estimates are:

$Z(t) = 2.2961 + 0.001896\, X_A(t) + 0.0263\, D_A(t) - 0.0032[F_A(0)-F_A(t)] + 1.30075\, AT$ -
(7.288) (2.584) (1.027) (-2.133) (3.361)

$-0.363\, X_A^2(t) - 0.000237\, D_A^2(t)\quad 0.01737\, [X_A(t)*D_A(t)]$
(-0.830) (-2.330) (-0.897)

$R^2 = 0.662$ $F=13.59$ $DW=1.967$ $n=62$

and

$Y(t) = 0.800263 + 0.001462\, X_L(t) - 0.007364\, D_L(t) + 0.000354[F_L(0)-F_L(t)] + 1.7962\, LT$
(2.685) (5.032) (-2.325) (1.789) (4.679)

$-0.2581\, X_L^2(t) + 6.8341\, D_L^2(t) + 0.97648\, [X_L(t)*D_L(t)] + 0.000461\, PP - 0.5732\, Y_L$
(-3.638) (1.701) (1.953) (2.259) (-2.821)

$R^2 = 0.7682$ $F=14.732$ $DW=1.914$ $n=62$

In both equations, numbers in parenthesis show t-values for the parameter estimate right above. All variables keep the same meaning as defined in the last section.

As can be observed the agricultural yield function yielded the expected signs for all the estimates. However, the estimates for deforestation (D_A) and the square of inputs (X_A^2) were not statistically significant. The statistical significance for D_A^2 confirms that deforestation increases agricultural production at a decreasing rate. On the other hand, the poor significance for the X_A^2 might suggest that the agricultural production function is not concave. However this result is likely due to the interval of values used for model fitting and to the way the inputs are estimated.

The production function for the stockbreeding sector shows several estimates with signs different to the expected ones. For instance, the estimates for D_L and D_L^2 show that the production function in the interval considered by the data set is convex with respect to deforestation, in other words, deforestation increases at increasing rates the stockbreeding production. In concordance with this behavior, the estimate for $[F_L(0)-F_L(t)]$ is positive, meaning that the forest lands incorporated to the stockbreeding production in fact are not marginal lands, but they increase production in this sector.

3.3. Simulation results

Once yield functions were estimated the so called "socially optimal" steady state forest stock (F^{**}) was computed by summing for all states the estimated optimal state level forest stocks from the forest land with likely agricultural use (F_A) and the forest land with likely stockbreeding use (F_L). These computations were accomplished by defining some values for the technological levels (same as the 1994's conditions), precipitation (average precipitation in the last 25 years) and by assuming that Y_L equals zero.

Table 1 shows the results obtained when different values for the prices of agricultural products (P_A) and real interest rate (r) are assumed. The column named original values shows the expected forest stock given the initial price relationship, while the following columns show the expected forest stock (with potential agricultural use) when the price for agricultural outputs is doubled ($2P_A$) and quadrupled ($4P_A$).

Table 2 shows the results obtained from simulations when different values for the prices in the stockbreeding sector (P_L) and real interest rate (r) are assumed. As in table 1, the column named original values shows the expected forest stock (with potential stockbreeding use) given the initial price relationship, while the following columns show the expected forest stock when the price for stockbreeding outputs is doubled ($2P_L$) and quadrupled ($4P_L$).

Table 1. Forest stock given different price rations in agricultural production

r	Original values	$2P_A$	$4P_A$
0.03	15080.132	14153.9998	11812.3216
0.05	12920.4475	10663.8107	3186.9745
0.07	9877.9857	4774.975	-25772.7836
0.09	5272.2308	-7286.4608	-
0.11	-2519.229	-46063.9709	-

Observe that in table 1 and table 2, forest stock shows only the area covered by forest with potential agricultural or stockbreeding production. In order to estimate the total forest stock values in both tables must be combined.

Table 2. Forest stock given different price ratios in livestock outputs

r	Original values	2 PL	4 PL
0.03	53565.921	53564.315	53561.101
0.04	38714.727	38712.834	38709.048
0.05	17426.557	17424.255	17419.65
0.06	-15641.449	-15644.388	-15650.266
0.07	-74006.858	-74010.92	-74019.044

These results show that interest rate has stronger effect on shifting forestland to stockbreeding production than on shifting forestland to agricultural production. This is likely due to the fact that livestock production yields higher returns than agricultural production per unit of land area, especially in forestlands, which happen to be marginal for agriculture but not for stockbreeding. The effect on prices is quite different, since a price increment in the agricultural sector has a stronger effect on reducing forest cover than the same proportional price increment in the stockbreeding sector. The result might be explained from the fact that cattle ranching is a very extensive activity, hence an increment in prices which, might be interpreted as a short run effect, does not change the stockbreeding production area. On the other hand, agriculture, which is an annual activity and more intensive than cattle ranching, do have a stronger impact from a change in prices.

The policy implication from these results show that an incentive program in the agricultural sector is more likely to produce more deforestation than and incentive program in the stockbreeding sector. In addition, the stabilization of real prices results in a fast reduction on the desirability to convert forestlands into grazing fields.

The next question is how sensible is the forestland to changes in forest products prices. One might expect that increasing forest products prices increase drastically forest cover. Table 3 shows these sensibilities when prices for forest products are doubled (*2 F*) or quadrupled (*4 F*). Notice the differential effect from the agricultural and stockbreeding sectors which is consistent with the result that marginal rate of transformation is larger for the stockbreeding and forestry sectors than for agriculture and forestry. Anyhow, increments in forest products prices have conspicuous effects on reducing deforestation.

The final parameter tested in the simulations was technological level. Table 4 and Table 5 show the effect of technology in the change of land use from forestry to agriculture y stockbreeding. Results show almost no effects from increments in technology level (either agriculture or stockbreeding) on changes on land use. This result just confirms that by increasing the productivity of current agricultural and stockbreeding land is possible to reduce deforestation induced by market causes.

Table 3. Forest stock given different price ratios for forest products

r	F_A/P_F	F_L/P_F	$(F_L+F_A)/P_F$	$F_A/2P_F$	$F_L/2P_F$	$(F_L+F_A)/2P_F$	$F_A/4P_F$	$F_L/4P_F$
0.03	15080.13	53565.92	68646.05	15080.14	53566.72	68646.87	15080.17	53567.11
0.05	12920.44	17426.55	30347.00	12920.46	17427.70	30348.17	12920.50	17428.23
0.07	9877.98	-74006.85	-64128.87	9878.01	-74004.82	-64126.81	9878.05	-74004.02

Table 4 Forest stock given different values in technology level of agricultural

r	Original values F_A	2 *AT*	4 *AT*
0.03	15080.132	15077.8221	15073.2024
0.05	12920.4475	12917.7468	12912.3454
0.07	9877.9857	9874.735	9868.2335
0.09	5272.2308	5268.1486	5259.9842
0.11	-2519.229	-2524.7157	-2535.6872

Table 5 Forest stock given different values in technology level in stockbreeding

r	Original values F_L	2 *LT*	4 *LT*
0.03	53565.921	53554.403	53548.651
0.04	38714.727	38701.147	38694.37
0.05	17426.557	17410.018	17401.773
0.06	-15641.449	-15662.598	-15673.045

Finally, all tables show that current forest stock conditions can be conserved at an interest rate ranging from 3.5% - 4%. Market conditions with interest rates above 5.5% lead to deforestation of current forest stock.

4. *Conclusions*

Results show the expected behavior of change of land use; the larger the interest rate the smaller the conservation motive and the smaller the amount of forest to be conserved. On the other hand, the greater the prices for agriculture and meat products, the greater the benefits from the change of forestland use which yield smaller forested areas. An important result derived from this analysis is that the stockbreeding sector deforest forestlands faster than the agricultural sector. In addition, forestlands incorporated to the stockbreeding sector remain highly productive at least for the time interval analyzed. On the contrary, forestland incorporated to the agricultural sector is highly marginal. This means that the stockbreeding sector is the one causing most of the reduction of the conservation motive, since makes more desirable the change of use for forestlands.

Unfortunately for forestry, increments in the value forest products (produced in the forest) do not have a strong effect on mitigating deforestation. That means that additional activities which might increase the per hectare value of forestry such as use of non timber forest products, hunting, and recreation, among others, have almost no effect on reducing deforestation.

One important extension of the model should be to evaluate the effect of policy reforms on the agriculture sector. These reforms consider the use of subsidies per unit of arable land for some crops as well as trading subsidies. These subsidies obviously will reduce the conservation motive lowering the desirability to maintain the forest stock. A more complete model should be developed to evaluate the impact of excessive deforestation rates on agriculture and livestock production by integrating the externalities and additional costs (caused by deforestation), directly into the production functions.

5. *Bibliography*

Aguirre, O., (1996), Dinámica de los agostaderos del Estado de México. Estudio Especial de Agostaderos. Programa de Modernización del SEDEMEX, PROBOSQUE, Metepec, Estado de México.

Adamson, M., (1997), Deforestación, producción agrícola y ganadería en Costa Rica, en: Calvo, E. Figueroa and J. Vargas Eds., Medio ambiente en Latinoamérica: Desafíos y propuestas, Univ. de Costa Rica, Univ. de Chile. San José, Costa Rica, pp 177-216.

Allen, J.C. and D.F. Barnés, (1985), The causes of deforestation in developing countries, *Annals of the Association of American Geographers* 75(2):163-184.

Barbier, Eb., J.C. Burgess and A. Markandya, (1991), The economics of tropical deforestation, *Ambio* 20(2):55-58.

Barbier, E.B. J.C. Burgess, J. Bishop, B. Aylward y C. Bann (1993), The economic linkages between the international trade in tropical timber and the sustanable management of tropical forests, ITTO Final report.

Binswanger, H. P., (1991), Brazilian policies that encourage deforestation in the Amazon, *World Development* 19(7):821-829.

Brown, S. and A. E. Lugo, (1992), Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon, *Interciencia* 17(1):8-18.

Brown, K. And D. W. Pearce (Editors), (1994), The causes of deforestation: The economic and statistical analysis of factors giving rise to the loss of tropical forests, UBC Press, Vancouver B.C., Canada.

Cairns, M.A. R. Dirzo and F. Zadroga, (1995), Forests of Mexico, *Journal of Forestry*, 93(7)21:24

Castillo, P.E., P. Lehtonen, M. Simula, V. Sosa C. and R. Escobar, (1989), Proyecciones de los principales indicadores forestales de México a largo plazo (1988-2012), Internal report. Cooperation Project Mexico-Finland, Subsecretaría Forestal, SARH, México.

Cavazos D., J.R., (1997), Uso múltiple de los agostaderos en el norte de México, *Ciencia Forestal* 22(81):3-26

Comisión Técnica Consultiva de Coeficientes de Agostadero (COTECOCA), (1994), Revegetación y reforestación de las áreas ganaderas en las zonas áridas y semiáridas de México, SARH.

Deacon, (1994), Deforestation and the rule of Law in a cross-section of countries, *Land Economics* 70(4):414-430.

Dotzauer, H., (1993), Los factores políticos y socioeconómicos que causan degradación forestal en la República Dominicana, Rural Development Forestry Network, Documento 16d., 20p.

Ehui, S. and T. Hertel, (1989), Deforestation and agricultural productivity in the Cot d'Ivory, *American Journal of Agricultural Economics* 71(3):703-711.

Ehui, S., T.W. Hertel and P.V. Preckel, (1990), Forest resource depletion, soil dynamics and agricultural development in the tropics, *Journal of Environmental Economics* 18(1):5-29.

Food and Agriculture Organization (FAO), (1993), Forest resources assessment 1990, Tropical countries, Forestry paper No. 112, Rome, FAO.

Food and Agriculture Organization (FAO)/ Instituo Mexicano de Tecnologia del Agua (IMTA), (1995), Base de datos agrícola. FAO Mexico Internal Report, Project No. UTF/MEX/030/MEX.

Hernández, X.E., T. Levy and L. Arias, (1987), Hacia una evaluación de los recursos naturales renovables bajo el sistema de roza-tumba-quema en México, In. H.G. Lund; M. Caballero, R. Villarreal (eds), Evaluación de tierras y recursos para la planeación national de las zonas tropicales, USDA For. Serv. Gen. Tech. Rep, WO-39 Washington, D.C., pp. 338-340.

Levy, T.S., E. Hernández X. and L. Arias R., (1987), Aprovechamientos forestales en el sistema de R.T.Q, In. Memorias X Congreso de Btánica. Soc. Bot. Mex, Resúmen No. 27 p. 225.

Masera, O. M.J. Ordóñez and R. Dirzo, (1992), Carbon emessions and sequestration in forests: Case studies from seven developing countries, Volume 4, E.P.A. Climate Change Division. Lbl-32665.

Oyama Homma, A.K., R. T. Walker, F.N. Scatena, A.J Conto, R. Carvalho, A.C. Rocha, C. A. Palheta, A. Moreira, (1993), La dinámica de deforestación y quemadas en el amazonas: un análisis microeconómico, Rural Development Forestry Network, Documento 16c.,16p.

Rzedowsky, J., (1978), Vegetación de México, Mexico city, LIMUSA.

Sánchez, P., (1976), Properties and management of soils in the tropics, John Wiley & Sons, New York.

Sánchez, V. A.S. and C.A. Ortiz S., (1991), El consumo de leña y su impacto sobre los suelos forestales del suroeste de Puebla, *Agrociencia Serie Rec. Nat. Renovables* 1(1):13-37

Secretaría de Asentamientos Humanos y Obras Públicas (SAHOP), (1981), Plano de políticas ecológicas y plano de vegetación y uso del suelo escala 1:4,000,000. México.

Secretaría de Agricultura, Ganadería y Desarrollo Rural (SAGAR), (1995), Anuario estadístico de la producción agrícola de los Estados Undos Mexicanos 1994, Secretaría de Agricultura Ganadería y Desarrollo Rural. Subsecretaría de Planeación, México, 698 p.

------------ , (1996), Compendio estadístico de la producción pecuaria de los Estados Unidos Mexicanos 1990-1994, Secretaría de Agricultura Ganaderia y Desarrollo Rural. Centro de Estadística Agropecuaria, México, 204 p.

------------ , (1998), Programa de Praderas y agostaderos 1995-2000, Secretaria de Agricultura Ganaderia y Desarrollo Rural. Comisión Técnica Consultiva de Coeficientes de Agostaderos, México, 100 p.

Secretaría de Agricultura y Recursos Hidráulicos (SARH). (1986), Información forestal de la República Mexicana. Subsecretaría de Desarrollo y Fomento Agropecuario y Forestal. INF, México, SARH.

------------ , (1990), Tabla de datos sobre perturbación forestal anual. Dirección de Protección Forestal, México, SARH.

------------ , (1992), Inventario nacional forestal de gran visión de México, Subsecretaría Forestal, México, SARH.

------------ , (1993), Sistema ejecutivo de datos básicos, Subsecretaría de Planeación, México, SARH.

------------ , (1994 a), Inventario nacional forestal periódico, Subsecretaría Forestal y de Fauna Silvestre, México, SARH.

------------ , (1994b), Compendio estadístico de la producción pecuaria de los Estados Unidos Mexicanos 1989-1993, Secretaría de Agricultura y Recursos Hidráulicos. Subsecretaría de Planeación, México, 53 p.

Quintas, I., (1996) Extractor rápido de información climatológica (ERIC): Manual del Usuario, Instituto Mexicano de Tecnología del Agua, Colección proyectos IMTA.

Toledo, V.M., (1990), El proceso de ganaderización y la destrucción biológica y ecológica de México, *Medio Ambiente y Desarrollo en México* 1(2):191-222

Vousden, N., Basic theoretical issues of resource depletion, *Journal of Economic Theory*. 6(1):213-224.