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Poverty and environmental degradation under trade liberalization: Searching for second-best policy options

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SUMMARY: Forest based agricultural systems in the tropics are being opened up to international trade at an unprecedented rate.This is the case of tropical agriculture in Mexico under the North American Free Trade Agreement (NAFTA), which is also having significant impacts on the decentralized land use decisions of small-scale farmers and on the natural resource base on which they depend. This paper develops a bioeconomic model of a typical forest-land based farming system that is integrated with the non-farm labour sector, as typically found in tropical regions. The data used to generate the simulations were gathered in two communities of Yucatan (Mexico) in 1998-2000. Through a system-dynamics framework, the agro-ecological and farming economic subsystems are integrated and the current situation of price liberalization that is negatively affecting soil capital and income levels is compared to a scenario that precludes an «optimal path to extinction» through careful policy intervention. This second-best case is based on a targeted policy mix that seeks to maintain the system viable for as long as possible above an irreducible poverty level. The policy intervention involves, simultaneoulsy, subsidizing off-farm wage rates, intensification of land use, and the control of households' rights to the forest commons. The model shows that such policy intervention can result in a large positive discounted net payoff basedon the increased incomes for the farming community after deducting the implementation costs of such intervention.

KEYWORDS: Liberalization. Land-use model. Slash-and-burn. Soil degradation. Rural poverty. Mexico.

JEL classification: Q12, Q23, D13, I3.

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Pobreza, degradación ambiental y liberalización del comercio: Hacia una intervención de políticas «second best»

RESUMEN: Los sistemas agro-forestales tropicales están siendo expuestos al comercio internacional a un ritmo sin precedentes. Este es el caso de la agricultura en México en el contexto del Tratado de Libre Comercio de América del Norte (TLCAN) que está teniendo impactos importantes sobre las decisiones descentralizadas de los campesinos y la base de los recursos naturales del cual dependen. El presente artículo desarrolla un modelo bio-económico basado en un típico sistema agro-forestal del trópico que, a su vez, se encuentra integrado con el sector laboral no-agrícola. Los datos empleados para generar las simulaciones han sido obtenidos en dos comunidades campesinas de Yucatán (México) entre los años 1998-2000. Mediante un marco teórico dinámico se integran el subsistema de producción campesina y el agro-ecológico. El objetivo es poder comparar la situación actual, con políticas macroeconómicas de liberalización de precios agrícolas (p.ej., maíz) que están afectando negativamente tanto el capital natural y el nivel de renta de los hogares campesinos, con un posible escenario basado en intervenciones de política económica con el objetivo de evitar una posible «senda óptima de extinción» del capital natural. Se trata de poner en práctica de forma simultánea varias políticas «second-best» manteniendo viable el sistema productivo durante el mayor tiempo posible y manteniendo, a su vez, los hogares por encima del umbral de pobreza. La integración de varias políticas implica (a) intervenir los salarios nominales fuera de la agricultura, (b) la intensificación del uso de la tierra, y (c) el control de los derechos de propiedad de los hogares sobre la tierra comunal. El modelo demuestra que este tipo de intervención «second best» es rentable si se tienen en cuenta la renta generada por las comunidades campesinas y el coste de la puesta en práctica de dichas políticas.

PALABRAS CLAVE: Liberalización. Modelo bio-económico. Roza-corta-quema. Degradación de la tierra. Pobreza rural. México.

Clasificación JEL: Q12, Q23, D13, I3.

1. Introduction

For the last couple of decades, the developing world is rapidly moving towards a free trade regime especially with regards to agricultural markets. At the same time, the concern for the impact of free trade on their environment is increasing. This is especially the case in biodiversity rich forested regions of the South. In the short run, trade liberalization may increase productivity and growth rates in the agricultural sector, providing for needed hard currencies through expanding export markets. However, the spread of such export markets also has a significant opportunity cost in terms of depreciating the natural resource base (e.g., soil, water, agrobiodiversity, etc.) or natural capital on which these economies largely depend (Barbier and Rauscher, 1994; López, 1997; Bulte and Barbier, 2005). Furthermore, since the rural poor are most dependent on this natural resouce base, it is therefore important to analyse the potential medium to longer run effects of liberalizing agricultural markets on the livelihoods of these farming communities.

The longstanding and contentious debate regarding the nature of the economic policies that can help improve farming communities' living standards while maintaining and even enhancing the quality of the natural resource base on which they depend needs to take into account the role of trade liberalization. An additional and closely related issue rests on the new Malthusian approach to understand the role of population growth on povertyand environmental degradation in developing economies (Dasgupta, 1992; Arrow, 1995; Grepperud, 1996). Linking these two approaches is fundamental to shed some more light about the likely dynamics that natural capital supporting agricultural productivity may experience in the coming decades. Trade liberalization and population growth causes both extensification and intensification of traditional agricultural systems. While extensification comes at the price of converting marginal lands like hillsides, forest and wetlands into agricultural land, unchecked intensification paths can also compromise agricultural sustanability in the longer term, as shown by the environmental problems arising after the Green Revolution in the South (Conway, 2000).

The stakes for the rural poor in an ever liberalized agricultural sector in the South are high and there is a need for devising clearer policy guidelines amidst the globalization of agricultural markets. Of course, policy instruments should be chosen considering different criteria, including economic efficiency, compatibility with other policies, enforceability, and political acceptability. Here we are mostly concerned with the first two criteria: efficiency and compatibility. The starting point is that combinations of policy instruments that can be describedas «one foot on the accelerator,one foot on the brake» should be avoided if a win-win scenario of increased welfare and decreased land degradation impact is to be achieved.

In this paper we focus on a typical forest based agricultural system that is widespread in the tropics, i.e: shifting cultivation (or slash-and burn) agricultural system. The problems of slash-and-burn agriculture *(SaB)* are often explained on grounds of excessive population pressure by agro-ecologists, and in terms of technical inefficiency by extension services. This paper focuses on identifying a complementary (second best) policy mix, including pricing incentives, population density control, and technical assistance to farmers to generate synergies that favour households' income levels and the state of the natural resource.

We develop a system-dynamics model that accounts for imposed socioeconomic status and inherent ecological restrictions of land quality for cultivation. Considering various parameters of land use, labor availability and economic demands, this model provides some perspective for slash-and-burn agro-ecological systems under an increasing liberaliztion of the staple, land and labour markets.

The model is built with socioeconomic and ecological data from two communities from Yucatan (Mexico) gathered between 1998-2000. The data are used to simulate two scenarios within an economic context determined by the strong liberalization policy thrust leaded by the Mexican Government under the auspices of the North American Free Trade Agreement (NAFTA).

The first of the two scenarios is based on the current situation where farmers are exerting an increasing pressure on the common property land resource, which in turn results in the so-called fallow crisis. This consists of a vicious circle whereby farmers shorten fallow periods, which impedes a sufficient recovery of soil fertility and forces farmers to clear more forest-land to maintain harvest levels, which in turn shortens fallow lengths further. The second scenario identifies the optimal policy mix that maximizes intertemporal societal welfare through increases in farm households' incomes, while ensuring that these are kept for as long as possible above an irreducible poverty level. This is done using a system-dynamics model of a representative household that extends itself to the community-level situation. By precluding any optimum path to extinction-type solution, ecological and social bounds to economic optima are made explicit.

In traditional *SaB* systems, households often rely on the sustainability of natural capital and the diversification of income sources between the on and off-farm markets. Our optimization problem is solved in the context of *SaB*. In particular, we use household and agronomic plot level data from two communities in Yucatan (Mexico). The case study is particularly interesting since rural Mexico, and Yucatan in particular, is undergoing significant changes given the liberalization thrust by NAFTA, which has not only affected the staple market but also has induced the flexibilization of the labour and land markets.

We investigate two possible scenarios under such a trade liberalization context: no government intervention and an agro-environmental scheme to maintain farmers' income and the conservation of the natural resource base in the coming decades. The policy variables considered in the model include: the staple price, the off-farm wage rate, the number of farming households, and the degree of technical intensification of the system (i.e., the proportion of labour invested in exploiting a plot of land rather than extending the plot by converting forest).

Given the multiplicity of the management intervention mix, we use a bio-ecomomic model of *SaB* as proposed by Pascual (2005) and Pascual and Barbier (2006; 2007). This set of complementary papers is referred to by *«PB»* in the remainder of the paper. *PB* yields the basic optimal control model that is used to develop the system dynamic framework presented here. Further, the latter complements *PB* by allowing the prediction of the optimal economic and ecological paths under additional constraints, especially by enriching the role of poverty in land use decisions under an increased liberalized market context. The imposed policy constraints allow us to try to find out the «second-optimum» solution. Since peasant economies usually have limited access to financial markets the government would need to allow peasants to keeptheir income above an absolute poverty-line. The idea behind the model is that in accordance with *PB*, the main driver of the agro-ecological state of the soil/biomass is the amount of labour put into farming, and thus forest clearing by shifting cultivators.

This paper proceeds as follows. The next section offers a review of land degradation models in the context of slash-and-burn forest systems. Section 3 outlines the modelling framework, while Section 4 puts into context the empirical data by describing the case study. The main simulation and optimizations results are reported and interpreted in Sections 5 and 6. Section 5 focuses on the modelling of a system where each household exploits the common agroecosystem in an optimal manner, avoiding both the reciprocal and intertemporal externalities that might be expected to affecta common property resource. Section 6 deals with a model where the same optimal strategy is followed, but the constraints under which the optimization is conducted are relaxed by governmental intervention. The last section draws on the results of the model and discusses the potential of government intervention to sustain farmers' income above the poverty limit and how it affects the socio-demographic and ecological dimensions of the community.

2. Land use models in slash-and-burn agro-ecosystems

Essentially, slash-and-burn, also known as *shifting* or *swidden* cultivation, in forested areas consists of clearing patches of primary or second-growth forest by cutting down the tree-bush vegetation and burning the woody biomass. This helps clear land from weeds and add needed additional reserves of soil nutrients to the crops through the ashes. Therefore, the nutrients accumulated in the top soil and in the vegetation itself during the fallow represent a *capital* gain for farmers (Nye and Greenland, 1960). After one or more years of cultivation, the farmer may leave the plot in fallow and allow secondary forest to return. After some time, the forest fallow is cut and the cycle begins again.

Traditionally *SaB* systems have been regarded as a wasteful system that cannot allow for sufficiently long forest regrowth intervals to replenish the nutrient stores. This effect, commonly known as the fallow crisis, implies a vicious circle of declining crop yields and the need to clear additional forestland area to achieve a minimum crop output. This idea is Neo-Malthusian in inspiration and is popular in the agro-ecologic literature (Sánchez, 1996). However, there have been few attempts to include a peasant behavioral component and market constraints to shed additional light on the fallowcrisis problem (Dvorak, 1992; Albers and Goldbach, 2000; Pascual, 2005; Pascual and Barbier, 2006; 2007).

The bioeconomic models used to analyze the main drivers of land degradation under *SaB* can be classified under three main branches. One focuses on the factors that make discontinuous (i.e., allowing for fallow periods) cropping shift towards continuous cropping. Among these factors, changes in population densities have been thoroughly looked upon (Salehi-Isfahani, 1988; Larson and Bromley, 1990; Barrett, 1991; Krautkraemer, 1994). The second branch is concerned with economic policy impacts on land allocation decisions. Under this analysis, it is important to consider whether the economic system is closer to the open economy scenario, or if, instead, the subsistence and risk-aversion (closer to Chayanovian models of farm households) strategies dominate households' decisions. While in the former scenario market signals guide farmers land-use decisions, in the latter, forest fallow management and area under cultivation become a function of family composition and resource endowments (Holden 1993; Walker, 1999). The third main branch takes a specific look at the *SAB* system by identifying the socially optimal land-use rules when households interact with each other in the sense that they all choose the area of cultivation from the same (common-property land) village boundary. Thus, bidirectional externalities due to the use of common property forest land are explicitly considered (Ehui *et al.,* 1990; López, 1997) address the productivity effect of using forest vegetation biomass at the village level.

The present paper draws from the insights arrivedat by these *SaB* modeling traditions. These models evaluate the sensitivityto various ecological and economic signals (such as output prices) of farmers' choices about the extent of cleared forested land and hence fallow periods and soil fertility. The system-dynamics model, outlined in the following section, recognizes that, in the use of common property land resources, there are (a) intertemporal private costs ofusing forest tree biomass to affect present and future soil fertility levels and (b) contemporaneous social costs due to the negative effect that clearing village-land has on other farmers. In other words, the model takes into account that depreciation ofvillage level forest vegetation biomass due to the farming activities by any single household contributes to a higher cumulative amount of converted forest-land in the community and hence a fall in agriculture yields in the future for all *SaB* forest users.

3. Model description

The system-dynamics model provides a numerical simulation platform for the analysis of the strategic problems surrounding the *SAB* community in their interconnected context. The methodology of system dynamics is particularly suitable for the modelling and analysis of meso-and largescale socio-economic or bioeconomic systems. Detailed descriptions of this methodology can be found in Forrester (1961, 1968) and Sterman (2000). It has been applied to many studies in the areas of environmental management (Mashayekhi, 1990), and ecological modelling (Wu *et al.,* 1993), regional sustainable development (Saeed, 1994; Bach and Saeed, 1992, Saysel *et al.,* 2002), and global environmental sustainability (Meadows *et al.,* 1992), among others.

The methodology focuses on understanding how the physical processes, information flows and managerial policies interact so as to create the dynamics of the variables of interest. The system's *structure* contains the relationships between these components and generates dynamic behavior (exponential growth or decline, S-shaped growth, collapse or oscillations). A system dynamics study focuses on explaining and predicting certain dynamics and identifying policies to improve the situation.

The stock-flow diagrams in Figures 1 and 2 summarize the main features of the system-dynamics model used[1]. The meaning and relationships of the acronyms in the diagrams will be explained in the following paragraphs. This works with three main types of variable. Stock variables (rectangles) arethe state variables and represent the major accumulations in the system. Flow variables (symbolized by circles) are the rate of change in stock variables and represent the activities that fill in or drain the stocks. The auxiliaries (in text only) are intermediate variables that affect the effect of the flow variables. Finally, the connectors (arrows) represent the cause and effects links within the model structure. The policy variables described in Section 6 are identified by shadowed backgrounds. The model was built using VENSIM DSS32 version 5.02.

The starting point of the present model is based on the control model by *PB*. This is a multiperiod agricultural household model that spells out the socially optimal conditions for the allocation of farm labour (control variable) and, indirectly, of soil fertility (state variable), which are both inputs in crop production under *SaB*.

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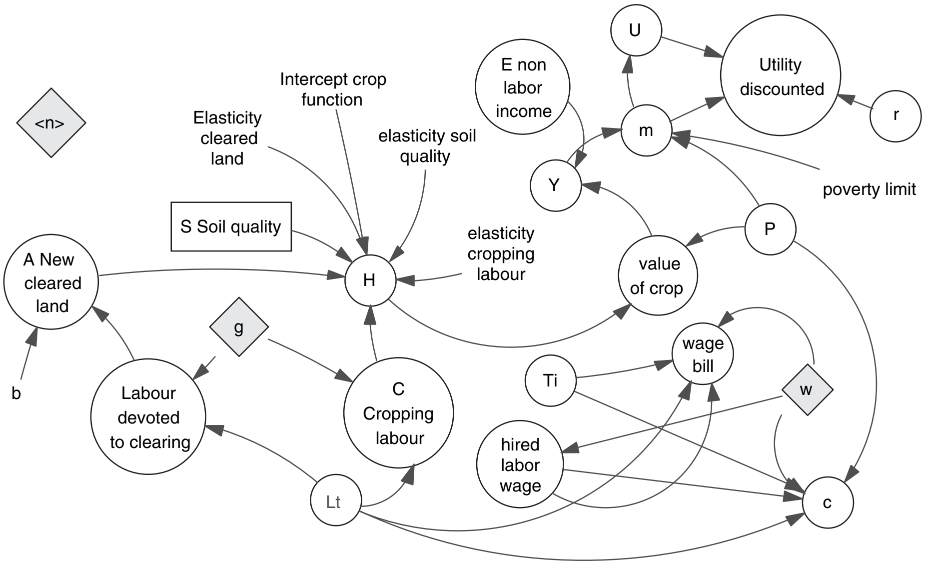
[1] A detailed description of all the stock-flow relationships governing the system or a transcription of all the equations involved is beyond the space limits of this paper, but is available upon request.

FIGURE 1

Simplified stock-flow diagram that describes the economic problem of the farming community



The present model complements the insights in *PB* by empirically solving for the optimal transitional paths of farm labour use, soil fertility, and all the associated variables. This assumes that the representative household devotes a socially optimal level of labor to cultivation and forest exploitation during periodically (each year). This could be because a social planner exerts some effective coercion on the individual households. An alternative, more realistic, explanation is that unwritten social rules could have evolved that force each household within the community to exploit the communal system in a socially optimal way, instead of in a privately optimal manner.

The main focus is on the potential policy instruments aimed at achieving ecological (in terms of soil fertility) and economic (in terms of households' income) sustainability. The basic setting of the model used to provide a context for the empirical system-dynamics model is as follows.

Consider *n* farm households[2] that gain utility from consumption of an aggregate staple good *(m)* that can be either produced or purchased in a competitive food market. The intertemporal problem of the representative household becomes the maximization of the present discounted value of utility by choosing the optimal amount of farming time, *L (t)*. Leisure is fixed, so it is not an argument of the objective function. The household problem is to:

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[2] Such that *n* grows, in principle, at an exogenous constant rate. Note that *n* was constant in PB.

$$\max_{L} \sum_{t=0}^{\bar{t}} \rho^{t}\, U\,[m(t)] \tag{1}$$

where the discrete-time discount factor is given by $\rho = 1/(1 + r)$, r being the periodic social discount rate. Households face three constraints: (i) a budget constraint, (ii) a technological constraint, and (iii) a soil-fertility dynamic constraint. The budget constraint (in real terms and excluding the household's i subscript):

$$Y\,(t)\,/\,P \equiv m\,(t) = H\,(t) + E + c\,[T - L\,(t)] \tag{2a}$$

where

$$H\,(t) = FA^{\beta_1}\,(t)\;C^{\beta_2}\,(t)\;S^{\beta_3}\,(t)\;e^{\mathrm{u}} \tag{2b}$$

represents a multiplicative staple harvest function, whose arguments are the area of new cleared land, *A, cropping* labour used in crop production on this land, *C,* and soil fertility, *S*. The *β*s are their respective elasticities and *F* is the total factor productivity under a random error term *u*. Soil fertility is included in the production function, since, in contrast to areas where land is homogeneous and in abundant supply, it is expected to be associated with a positive marginal value. Hence, the household's real income *(m)* consists of the output of the staple crop *(H),* plus real (price deflated) non-labour income *(E)* and the real wage bill. This is the off-farm labour income given the exogenous real wage rate *(c/P)* and the household's predetermined endowment of labour time *(T)*. *A(t)*, the forest plot cleared during each period by the representative *SaB* household, is given by the ratio of (i) the total labour put into cropping *gL(t),* where *g* (such that $0 < g < 1$) is the proportion of farm labour in forest felling activities, to (ii) the effort intensity *b* in felling forest land (e.g., hours needed to clear one hectare of tree biomass). Hence[3]: $A\,(t) = \dfrac{gL\,(t)}{b}$. Field-work research suggests that, on average, only 29% of the land cleared on the previous year is reused during a second cycle (Pascual, 2005). This assumption is incorporated in the model.

Based on Nokoe's (1993) work on tropical forest biomass growth, *B(t)* is calibrated in the field using the Verhulst logistic growth model, to then link it with farmers' land use strategies (Eq. [A3] in the Appendix):

$$B\,(t) = B_{max}\,\{1 + e^{\gamma\,(\tau' - \tau)}\}^{-1} \tag{3}$$

where B_{max} is the carrying capacity of biomass (in tons/ha), γ is the intrinsic constant growth rate of biomass, and τ' represents the fallow duration (τ) when $\dot{B}$ is maximum.

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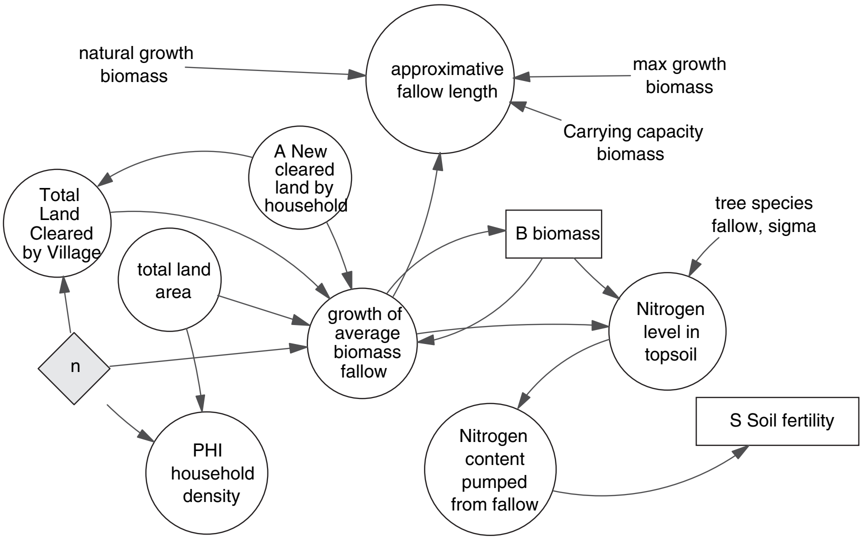
[3] Departing from *BP*, the present model allows for *g* to change through time, *g* also depending on the average age of the household. Hence $A\,(t) = \dfrac{gL\,(t)}{b}$.

FIGURE 2

Simplified stock-flow diagram that describes the biological process involved in *SaB* farming



The dynamic soil fertility constraint is determined by the current state of forest biomass, $B(t)$, in a slash-and-burn system, approximated in discrete time, as in Equation [4]:

$$\Delta S(t) = \lambda\,[\gamma\, e^{-1/B(t)} - \Phi(t)\, A(t)] \qquad [4]$$

$S \equiv S(t+1) - S(t)$ is the discrete increment of soil fertility between two contiguous time periods. B is the standing biomass of the forest plot to be converted at instant t, Φ stands for household density, which in contrast to *PB* is not restricted to be a constant over time. λ translates $N(t)$ stored in the biomass into soil fertility. It is clear that by making $\dot{S}$ depend on $A(t)$ and thus on $L(t)$, the evolution of the state of the agro-ecoystem becomes a function of economic and technological conditions. The constant natural growth rate of the standing tree biomass in the forest is γ[4].

The equation of motion for soil fertility is derived by noting that the fundamental natural asset in *SaB* is the soil fertility/above-ground tree biomass complex. Following Trenbath (1989), soil fertility is proxied by the nitrogen content in the topsoil, $N(t)$. It is assumed to be maintained only through fallowing (with no need for activities such as the application of mulch, dung, or crop residues). $N(t)$ evolves as a *by-product* of forest dynamics during the fallow (Nye and Greenland, 1960). The equation of motion also takes into account that soil fertility in a recently cleared forest plot depends on: (i) tree biomass during forest fallow prior to clearing (Trenbath,

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[4] Refer to the Appendix for the derivation of the state equation and full notation of the model.

1989), and (ii) the species composition of the tree biomass in fallow (Kleinman *et al.,* 1995). Furthermore, it is assumed that in an early fallow the rate of accumulation of *N(t)* by the biomass and in the soil is at a maximum, and that there is an asymptotic approach to high levels of soil fertility under long forest fallows (Nye and Greenland, 1960). *PB* use the idea proposed by López (1997, 1998) by making the evolution of tree biomass on a plot of forest-land to depend on the remaining area of fallow land available to the whole village. The maximum principle of the optimal control problem yields an optimal rule for the allocation of farm labour *(L)* (see Appendix) towards a long run steady state equilibrium. Departing from such a long-run framework, we determine the time horizon $\overline{t}$ endogenously. The time frame $\overline{t}$ is given when either of the following two cases occur: (i) soil fertility has been totally depleted, and hence the ecological subsystem has collapsed from an ecological perspective, or (ii) the real income of the representative farm household falls below the absolute poverty line, which implies that the *SaB* subsystem has collapsed in economic terms.

4. Case study description

The data used to simulate the model were collected between 1998 and 2000 in the municipality of Hocaba. This is one of the 106 municipalities of the State of Yucatan[5] and it is well connected by road to the capital, Mérida, 55 km to the North-West of Yucatan. The forest vegetation in the municipality is characteristic of a warm sub-tropical climate. This climate has determined the structure of the forest vegetation: an ecotone of low-to-medium height tropical dry deciduous forest (Mizrahi *et al.,* 1997) The ecological characteristics of the area have also determined the farming practices of the Yucatec Maya living in this and the surrounding communities. They practice the *SaB* system, locally known as *milpa,* to produce maize as the most important crop grown, usually for home consumption. The milpa system is mostly practised in the community's ejido or common property land, which is controlled by a comisario ejidal (or ejidal chief) elected by the farming community.

In 1998 there were approximately 1,035 households living in the municipality of Hocaba with 60% being actively engaged in clearing forest through *SaB*. The average family size was 5 members per household. Interestingly, the *SaB* population density is 6 households per km^2 (Pascual, 2002), which, according to Mizrahi *et al*. (1997) is well beyond the maximum viable population density concerning the ecological integrity of the agro-ecosystem.

As far as poverty levels are concerned, average income is $4,665 (about US$485)[6], *per capita per annum* (pcpa) with 21% of households lying below the most extreme poverty line, determined by the expenditure needed to achieve a mini-

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[5] The State of Yucatán, the State of Campeche to the Southwest, and the State of Quintana Roo to the South and Southeast, form the Yucatán Peninsula, which limits to the North and Northwest with the Gulf of Mexico.

[6] Throughout the paper, $ will refer to Mexican pesos. In 1998, $9.21 = USD.

mum nutritional requirement, i.e. \$2,376 pcpa or US\$ 258 pcpa (Pascual, 2002). This implies that the minimum acceptable dietary requirement, i.e. m, for the representative household is just over 7,750 kg of maize/year[7].

It is worth noting that in the imputed income from *SaB* constitutes a 8% of total disposable income. Around 19% comes in the form of government transferences,and the remaining income is due to off-farm activities carried out mostly in the capital, Mérida. In fact, 60% of the peasant households had one or more members employed at some time or other during the year in theoff-farm labour market (Pascual, 2002). Besides the relative low imputed value of agricultural output, this is extremely important because of its role in food security. Maize yield ranges between 500-600 kg/ha, which is substantially less than the average of 2.3 tons/hain Mexico in1998 and a minuscule figure if compared to capital intensive maize farming in neighboring US (i.e., 8.5 tons/ha) (FAO, 2002).

In terms of the farming technology, as the natural soil conditions generally do not allow for mechanization, the milpa has remained labour intensive. In general, households adjust the calendar of milpa activities according to the sequence of the first rains, the mid season drought, excess moisture in September, and other constraints mostly marked by labour availability due to the usually better remunerated off-farm labour participation.

It is important to note that maize prices have already been falling, although import liberalization will not be full until the year 2008. In addition, due to NAFTA farmers are becoming better integrated with emergent labour markets thus increasing the options to seek additional income from off-farm labour. This offers the government the opportunity to tailor complementary economic policies that can help to reduce some pressure on soil capital. For instance, the «maquila» industry plants are moving to rural areas further from the Mexican northern border, such as Yucatan, which pushes up wage rates for skilled manual labour (e.g., by females working in the textile industry as opposed to the crafting industry). Last, but not least, the amendment of Article 27 of the Mexican Constitution in 1992, induced by pre-NAFTA negotiations, has resulted in a thriving land market. However, it has also undermined the ejido: the traditional institution that granted peasant communities access to communal land tenure. These sudden changes in the rural context will have direct effects on the labour and land use patterns by poor households (Dyer *et al.,* 2004).

5. Optimal land use under no intervention (BOM)

The first of the two models simulates the socially optimal dynamics of the system under an *open-economy* scenario, as theoretically modelled by *PB*. Since leisure is not an argument in the utility function, on-and off-farm labour allocation is determined by the movements of the wage rates and not by the balance of marginal disutility of effort and the marginal utility of product. This also implies that labour choices are

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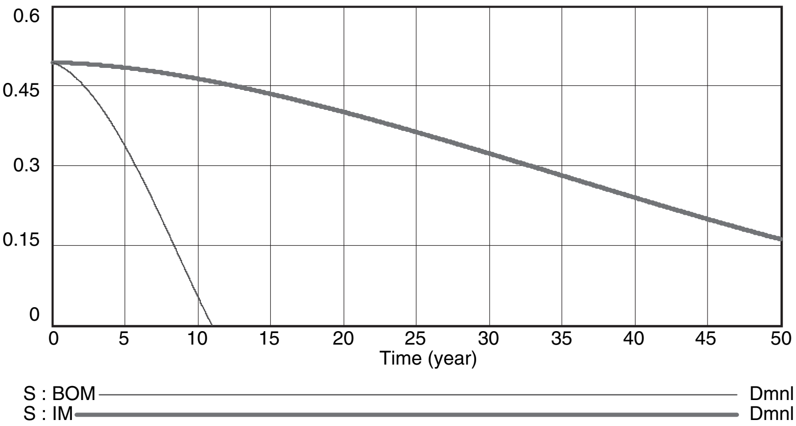
[7] Of course, other foods are included when calculating the official poverty line. However, in rural Yucatán, maize is the predominant staple in daily meals.

not dependent on the household's demographic structure (Benjamin, 1992). In other respects, the usual assumptions pertaining to the open economy case are still assumed to hold (Singh *et al.,* 1986)[8].

The β production elasticity parameters associated with each of the three inputs are 0.98, 0.25 and 0.56 for *A, C, and S,* respectively (Pascual and Barbier, 2007). Apart from all parameter values gathered from the field, the simulation of the model begins with the observed field values for $S_{t=0} = 0.49$ and $L_{t=0} = 639$ hours/year/household, or equivalently, 21.2 dyh *(days/year/household member)*[9]. Under the optimal social behavior by the community, the model predicts that the system will last just under 11 years, since soil fertility would be optimally exhausted (Figure 3). If current price and population parameters remain unaltered in the future, and only the control variable *L* can be adjusted. In fact, it can be seen that *L* first increases at a decreasing rate until 167 *dyh* (Figure 4). This implies that in the fourth year households begin to hire in farm labour, because all their disposable labour time is devoted to farming. Hence, they completely leave the off-farm labour market in the 4th year. Even if hiring in labour cuts into their cash budget with a negative average wage bill, this is compensated by crop production. Also in the sixth year, production of maize begins to decline from almost 5 tons of maize by clearing approximately 6 hectares of forest-land. As shown in Table 1, yield levels are maximized in year 3 at 925 kg/ha, substantially more than in $t = 0$,(575 kg/ha).

FIGURE 3

Soil fertility



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[8] The critical assumptions in the model are that: (i) no difference exists in terms of utility between engaging in on-and off-farm labour, (ii) farm and hired labour in farm production are perfect substitutes, (iii) financial markets exist that allow households to smooth consumption patterns intertemporally.

[9] This corresponds to an average o 6 hours/day.

FIGURE 4

On-farm labor allocations

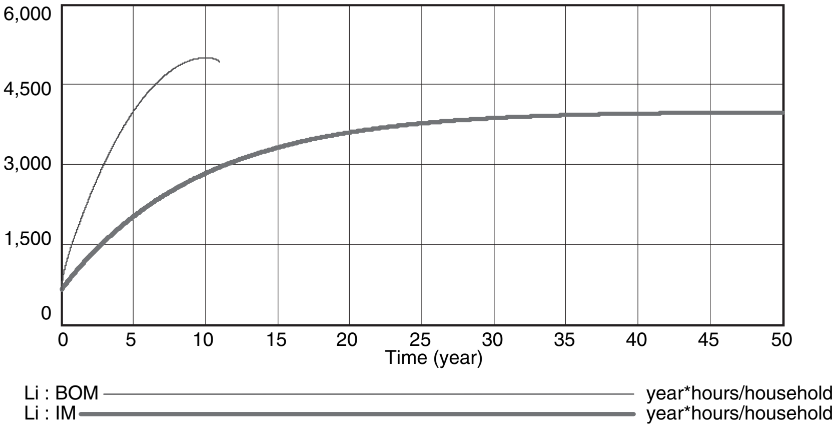


TABLE 1

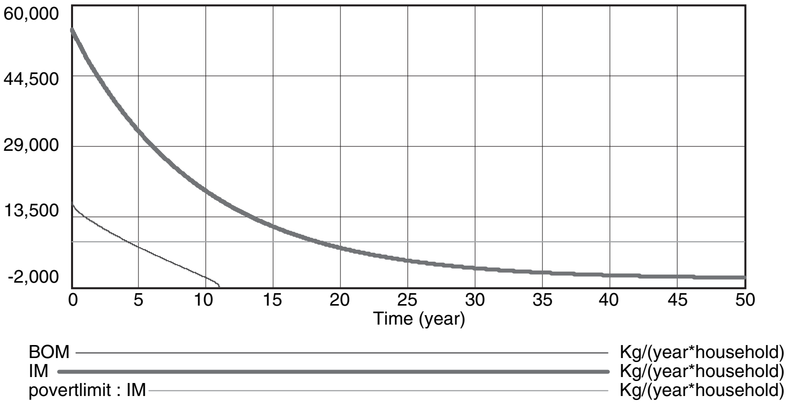
Summary of results Basic Optimal Model BOM

	BOM			
Variables	**Mean**	**ST Dev**	**Min**	**Max**
Farm labour (hours/year)	4,177	1,228	638	5,002
Wage bill (in $)	–23.94	7,732	–7,837	19,644
Soil fertility (from 0 to 1)	0.29	0.1527	0	0.4943
Fallow time (years)	6.706	5.809	0	16.11
Real income (kg of maize)	6,379	4,764	-1,952	16,647
Maize harvest (kg)	3,478	1,269	0	4,892
Maize yield (maize kg/ha)	722	218.57	8.802	925.93
Plot area (ha)	5.10	1.663	0.8643	6.777
Number of households (n)	471.76	22.39	433	510.52
Off-farm wage ($/hour)	6.24	n.a.	n.a.	n.a.
Proportion of *L* felling (g)	0.5963	n.a.	n.a.	n.a.
Maize price/kg	1.5	n.a.	n.a.	n.a.

Assuming that household population is exogenous (apart from natural growth) during these 11 years, the income earned by the households falls below the poverty line in the 4th year (Figure 5). Thus, during the first four years, households need to plan consumption patterns to avoid falling below the extreme poverty line from the 4th to the 11th year. However, it can be calculated that during the whole planning horizon only 1,300 kg of maize *pcpa* can be consumed. This is lower than the poverty line implying that, even if credit markets were available for peasants to smooth their consumption patterns, the system would not support levels of minimum consumption. This is predicted even if the households act in a cooperative non-myopic manner. Hence, there is clear rationale for policy intervention to maintain households' minimum consumption requirements.

FIGURE 5

Income versus poverty limit



6. The socially optimal land-use under intervention (IM)

As explained above, the existence of smooth credit markets may not suffice if the government deems necessary to allow the cooperatively-behaving farmers to average a minimum standard of living. The government could, instead, resort to other market-based mechanisms to keep households above the specified poverty line, at least for some pre-specified period of time. Here we study the potential of institutionally altered real wage rates, by either reducing staple prices or by subsidizing nominal off-farm wage rates.

Obviously, if the peasant community worked efficiently, it could also regulate its members' access to the forest resource. In this case, at least in principle, the community could restrict access to the common-pool resource by setting up some pre-specified compensation mechanism to those households that would voluntarily relinquish their rights to use the forest vegetation by slash-and-burning it. In addition, households themselves would try to control their farming activities so that total overall discounted utility (a function of aggregated on-and off-farm income in this case) were maximized. In addition, farmers, persuaded by well designed extension services by the government could in principle increase the level of labour (versus land) intensification in farming. That is, they could increase the proportion of farming time spent not clearing forest land but cropping (weeding, sowing, etc.) in the already cleared forest plot[10].

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[10] In Yucatán efforts to intensify the milpa by reducing burning of swidden plots and encouraging green manuring (with the leguminous *Mucuna), Mucuna pruriens*, has been successful for weed control, and the use of crop residues to increase organic material in the soil. However, this intensification method has not been widely applied by peasants.

We have therefore identified three important mechanisms that would stretch the sustainability of the system for as long as possible while keeping farmers above a pre-specified poverty line: (i) the number of households that keep the right to exploit the soil resource at time $t = 0$ (n_0)[11], (ii) the total farming time and its intensification level *(g)*, and (iii) the government's nominal wage *(w)* subsidy level. The new control policy variables and the resulting complementary state and control variables are denoted by an asterisk (*). Of course, the government would only apply a mix of these social policies if it is profitable: if the benefits to the community outweigh the costs.

The benefit of the policy is given by the difference between the present value income for the n^* remaining households after the policy has been effected, and the present value income for the n households previous to the policy prescription:

$$\sum_{t=0}^{\bar{t}} n^*_t \rho^t Pm^*(t) - \sum_{t=0}^{\bar{t}} n_t \rho^t Pm(t) \qquad [5a]$$

where, $r = \frac{1}{1+r}$ is the discount factor. There is the financial cost to the government, due to the subsidized wage payments[12] to the n^* remaining households:

$$n^* \sum_{t=0}^{\overline{t^*}} \rho^t (w^* - w) \left\{ \left[(T - L^*_t)_{\ [T-L^*_t]>0} \right] - \left[(T - L^*_t)_{\ [T-L^*_t]<0} \right] \right\} \qquad [5b]$$

Therefore, the net payoff of the policy would be given by:

$$\widetilde{P} = \sum_{t=0}^{\overline{t^*}} n^*_t \rho^t Pm^*(t) - \sum_{t=0}^{\bar{t}} n_t \rho^t Pm(t) - n^* \sum_{t=0}^{\overline{t^*}} \left| \rho^t (w^* - w)(T - L^*(t)) \right| \qquad [6]$$

where the | | denotes *absolute value*. If the payoff is positive, the policy would result in a Pareto improvement[13]. However, given the social nature of the measure, if the Hicks-Kaldor test is passed, the benefits accruing to the remaining households (or a part thereof) would need to be used to compensate the $(n - n^*)$ households who had relinquished their farming rights in the common property forestland during the first period $(t = 0)$. The full compensation, would be given by:

$$(n - n^*) \sum_{t=0}^{\bar{t}} \rho^t \left[PH - w(L - T)|_{L-T>0} \right] \qquad [7]$$

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[11] After $t = 0$ this number would be allowed to increase at the exogenous rate of demographic growth in the community.

[12] Note that the subsidy applies to both off-farm and on-farm wages, which, under the assumption of frictionless markets, converge in long-run equilibirum, albeit to a locally one.

[13] However, evenif net social benefits arenegative underthe current policy froma political standpoint the project could also see the «go ahead». This is simply because for the government this policy is an imperative one, unless it agrees on leaving farmers to starve!

which is the net opportunity cost of farming time for the evicted households. Note that it is a *net* fund, because it takes into account the cost of hiring labour to get the realized harvest *(H)*, provided these households hired in labour before the policy was applied and because it is net of exogenous payments, *E,* which are unrelated to the rights of access to the common land. If the payoff was not enough to cover this compensation fund, the government would need to finance it and the government's budget and political will would determine the desirability of the policy.

This results in an equivalent measurement of the overall net benefits of the policy:

$$\begin{aligned}\widetilde{P} = {} & \sum_{t=0}^{\overline{t^*}} n_t^* \rho^t P m^*(t) - \sum_{t=0}^{\bar{t}} n_t \rho^t P m(t) \\ & - n^* \sum_{t=0}^{\overline{t^*}} \left|\rho^t (w^* - w)(T - L^*(t))\right| \\ & -(n - n^*) \sum_{t=0}^{\bar{t}} \rho^t \left[PH - w(L - T)|_{L-T>0}\right]\end{aligned} \tag*{[8]}$$

This means that the government would evaluate the overall welfare enhancement triggered by the policy accounting for the effects on three different agents: the evicted households (who would receive a compensation equal to what they could expect from access to a non-intervened system), the remaining households (who would earn higher incomes under the intervention), and the taxpayers. The system has been numerically simulated to find the longest number of years that the optimal number of farmers could be kept optimally over the poverty threshold at the lowest possible cost for the taxpayer by choosing: (i) the nominal wage rate, w up to a maximum of \$25/hour, which is the maximum nominal wage reported by households in the field (Pascual, 2002), (ii) the proportion of labour time used in clearing rather than cropping, g (from 0.1 to 0.99), and (iii) the number of households exploitingthe system (witha minimum n^* of 50 households)[14].

The optimization IM is conducted using as the objective the product of the *Pareto-improvement* payoff $\widetilde{P}$ as defined in Equations [6] and [8] above times the number of years during which the system kept of providing the farmers with a socially acceptable income level $\underline{m}$.That is, under scenario *IM,* it was assumed that the government followed a maximization problem of the type:

$$\begin{aligned} & \max_{w,g,n} U' && = && \widetilde{P} \cdot \overline{t^*} \\ s.t. \quad & m(\overline{t^*}) && > && \underline{m} \end{aligned}$$

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[14] 50 households is an arbitrary number and used for expository reasons.

The results of the intervened model suggests that the shifting cultivation can be sustained for over 18 years by simultaneously applying the following measures in the *SaB* system. The first measure would be to subsidize the nominal wage rate w to increase it almost up to the prespecifed maximum: w = \$24.76/hour, from the current \$6.24/hour. Farming of land already cleared should be intensified (reducing g from 60% to the nearly minimum, i.e. g = 10.41%). Finally, in $t = 0$ the number of farming households should be reduced to 366 (therefore requiring that some 67 households relinquish their land use rights) so that only these 83% of households keep their rights for farming in the common property land at $t = 0$.

TABLE 2

Summary of results Intervened Model IM

Variables	**IM**			
	MEAN	**ST DEV**	**MIN**	**MAX**
Farm labour (hours/year)	3,370	818.54	638	3,974
Wage bill (in \$)	9,601	20,271	-5,365	77,268
Soil quality (from 0 to 1)	0.3521	0.104	0.1614	0.4943
Fallow time (years)	8.521	5.127	0	16.11
Real income (kg of maize)	10,188	13,354	58.56	54,716
Maize harvest (kg)	870.62	200.87	221.8	1,062
Maize yield (maize kg/ha)	1,115	176.06	765.43	1,900
Plot area (ha)	0.7959	0.1933	0.1506	0.9387
Number of households* (n)	515.11	86.11	365.97	664.24
Average off-farm wage*	24.76	n.a.	n.a.	n.a.
Proportion of *L* in felling (g)*	0.1041	n.a.	n.a.	n.a.
Maize price/kg	1.5	n.a.	n.a.	n.a.

Table 2 and Figure 5 show that the income of each household left in the milpa system[15] is substantially increased by the regulatory policy relative to the base case[16]. The cumulative aggregate nominal discounted income would increase from \$40.72 million to \$270.77 million. If the government deemed desirable to go ahead with this policy of concentrating the rights to exploit the system in the hands of less households in $t = 0$, the cumulative, up to $t = t^*$, value of the wage-subsidy bill would be equal to \$102.51 million. This results in a net payoff, $\widetilde{P}$, equal to \$127.54 million, as per Equation [6], before compensation to evicted households. Even if the government financed the additional aggregate compensation payment of \$4.273 million to the 67

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[15] And those who enter after the expulsion in $t = 0$.

[16] Note that the calculation of the cumulative income obtained under regulation considers also those periods after $\overline{t}^*$. Given that the policy results in a system that sustains farming for quite a number of years afterwards, more income could be generated by the households, if they decided to continue cultivating milpa after $\overline{t}^*$. However, even if counted in, this income would enter the calculation with an increasingly high discount factor.

households evicted (as per Equation [7]) in $t = 0$, the final net payoff would be \$123.26 million: the policy clearly results in a worth while Pareto improvement. This would be the case even if soil fertility undergoes a steady decline (Figure 3). Figure 6 shows the evolution of the discounted utility for the average households under BOM and IM.

FIGURE 6

Discounted utility

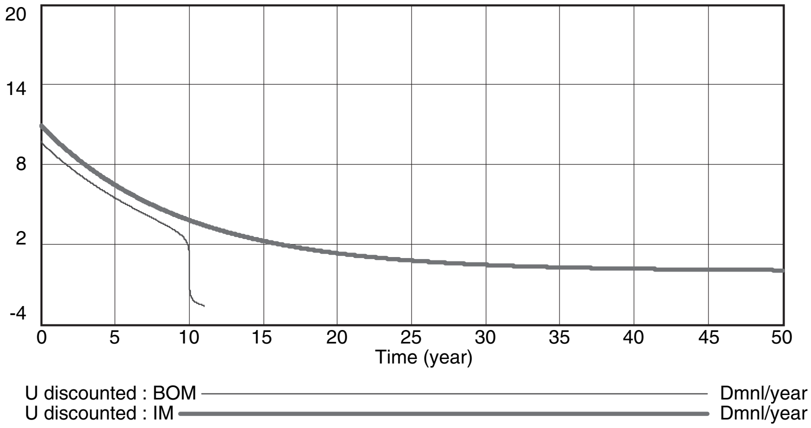
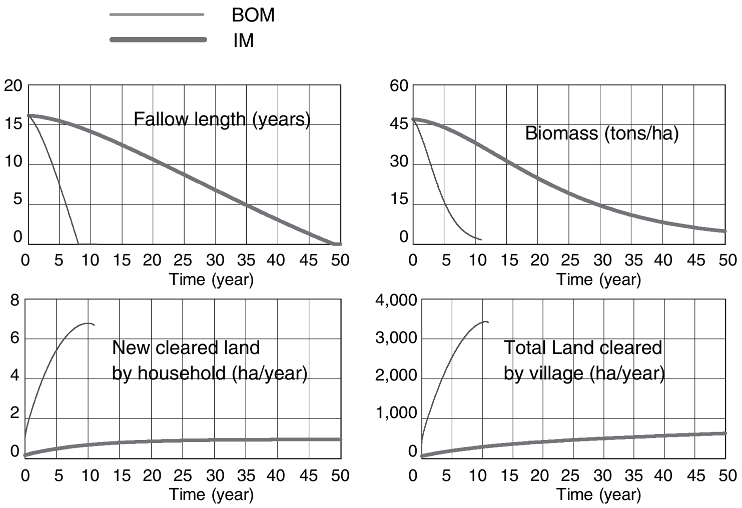


Figure 7 shows how the main variables of the ecological system evolve under policy intervention compared to the actual situation without intervention. The actual (predicted) scenario shows that the average fallow period and hence forest biomass levels in the community would fall fast due to a rapid (optimal) increase in total land cleared in the villages commons. The optimum policy mix would allow the decrease in fallow time and biomass to occur more slowly throughout a larger period of time since farmers would find it optimal to clear less land. This is due to the application of less time in clearing forest land relative to labour invested in cropping activities in the already converted forestland. Additionally, the rate of increase in land clearance by the representative household is lower than under no policy intervention. This results in higher soil fertility levels and the stretching of the viability of the ecological system.

The evolution of the relevant variables of the socio-economic sub-system is described in Figure 8. It can be seen that the system can be sustained for several decades, but it should be pointed out that in reality the system under intervention would collapse earlier. This is because income (Figure 5) falls below the subsistence level in the 18th year. Under the no policy scenario *(BOM)*, yields increase to almost a ton and under the optimal soil fertility, converted land area and labour applied, total harvest would increase up to 4.5 tons before they begin to decrease again due to rapid decreases in soil fertility. By contrast policy intervention allows yields to increase in the

FIGURE 7

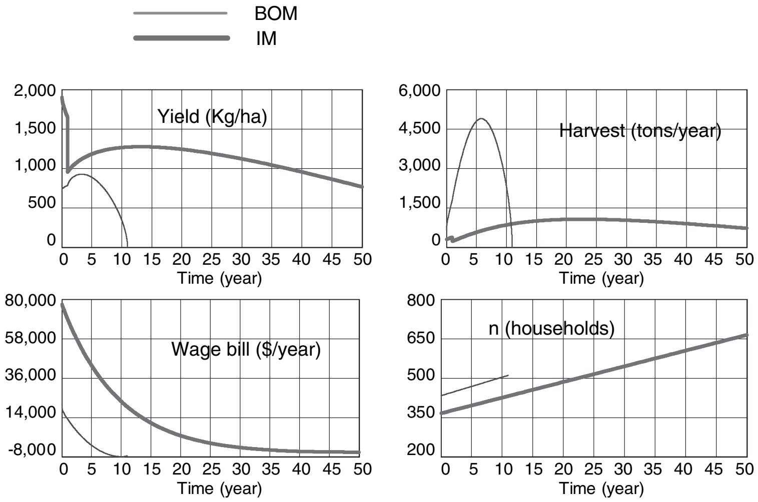
Evolution of fallow length biomass, total land cleared by the village and new cleared land by the household



short run through land use intensification and then to be maintained in around a ton/ha. Because the policy mix prompts households to choose to clear less forest land area and conserve greater soil capital, total harvest increases until the 18th year obtaining just above a ton of maize. It can also be observed, that under intervention, households have a higher wage revenue due to a large share of their disposable labour time allocated to the off-farm.

FIGURE 8

Evolution of yield, harvest, wage bill and number of households



It is apparent that under conditions of uncertainty about the conditions of the off-farm labour market, a certain element of inequity is generated by the policy described above. This is because at time $t = 0$, the households who are asked to leave the systemare offered, as a compensation, only the net returns they would have typically obtained if no household left the system. Therefore, the compensation scheme guarantees that, if they agree to leave, they cannot be worse-off than they would be under a *BOM* scenario. In addition, they now have available their labour to supply in the off-farm market. It would be possible for these evicted houses to add non-farming labour revenue to the compensation received from the public agency[17].

However, non-skilled labour may find it difficult to relocate into the non-farm labour market, so farmers leaving the system may not be able to complement their compensation payments to equal the average of the remaining *SaB* farmers. This could eventually make the idea unfeasible from a political standpoint. The farmers perceive that there is more uncertainty about the prospect of finding a good enough job in which to employ their labour time than about the improved returns of an intervened milpa system. Therefore, a more practical difficulty would arise if no farmers accepted the offer to leave the system.

7. Conclusion

Globalization of agricultural markets and deepening international trade in staple crops are almost sinonimous terms when referred to traditional rural economies in the tropics. Their long term effects on the natural resource base on which agricultural productivity rest are not well known. Most theoretical studies on the economics of forest based shifting cultivation under open economies are few and mostly discuss the effects of population pressure and the effects of changes in output prices. In addition, given the specific characteristics of fallow-crop rotation systems, most theoretical analyses have focused on the optimal rotation, and within this context some ecological models have been developed to analyze the effect on the dynamics of soil fertility.

The system-dynamics model developed here recognizes that the farming economy and the state of the forest biomass/soil fertility are jointly determined systems. Further, the effects of policy liberalization, both on output and inputs need to be taken into account. One key input is agricultural labour. Indeed, scale of labour allocation in extensive *SaB* is such that this matters for the sustainability of the system. The model presented here thus looks at optimal labour allocation decisions in the context of open labour markets, where off-farm labour supply is also an option. Notwithstanding the importance of integrating the labour and land use decisions, a limitation of this model is that discontinuous changes around critical ecological thresholds for the functioning of the shifting cultivation system have not been considered. Understanding such potential discontinuities is also important to design policy that assures the sustainability of desirable states through investing in the resilience of the system (Arrow *et al.,* 1995). Nevertheless, the model shows only local potential sta-

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[17] Which would be less, as seen above, than the minimum poverty threshold.

bility, since this agro-ecosystemcan collapse both economically (labour use is driven to zero while soil fertility reaches its carrying capacity) or ecologically (soil fertility is exhausted through excessive use of extensive farm labour). It is because the system shows such fragile stability that policy intervention is relevant, especially when farming decisions are left to market signals.

This paper provides some insight on the design of policies to maintain the productive potential of a typical tropical slash-and-burn system that is well integrated into the non-farming economy. When soil degradation due to market and population pressure is a real threat to the survival of the agricultural system, governments need to find suitable policies to address the ecological problem. In addition, governments must find the policy instruments that avoid negatively affecting poor farmers' income levels.

Using household and plot level data from Mexico, the effectiveness of various of such policy options is addressed. The analysis is based on a system-dynamic approach to reflect the feedback effects between the main control mechanism of the shifting cultivating household, on-farm labour, and soil fertility. In order to better grasp the optimal responses by forest users to changes in market signals largely affected by trade liberalization through NAFTA, suchas prices or wages, we presenta bioeconomic system-dynamic model in which on-and off-farm labour use decisions are intrinsically interdependent.

The model has is solved from a socially optimal perspective, given the demographic, ecological and market conditions. We show that further Pareto improvements can be achieved by governmental policies that promote a more efficient use of labor farm (increasing the proportion of cropping labor relative to clearing labor), while reducing the access to the milpa system and increasing wages. These policies would also delay the ecological collapse of the system. This reveals that the inefficiencies that would persist in the system under the constraint of a fixed number of households could be corrected if flexibility were introduced in terms of access to the system, by reshaping the rules about accessto the common property resource. Social welfare could be improved if an appropriate mechanism for compensating the evicted households were in place. The model also shows that the expected decrease in maize prices due to NAFTA in Mexico, by increasing the real wage rate, can aid to both sustain the productive potential of the agro-ecosystem and increase households' income levels in both the short run and long run.

It is important that the model assumptions are acknowledged when interpreting the results. For instance, we assumed that farmers have limited discretionary time to allocate labour out of the milpa and the off-farm labour sector. One could argue, however, that given the complex livelihood strategies of the poor, they adapt to changes in the key parameters of the system by reallocating labour to or from other resource-based agricultural activities, such as fuelwood collection, hunting and home-garden husbandry. In our case study area, resource-based activities other than milpa take a small proportion of total disposable time. However, in other areas where poor households adapt to changes in the key parameters of the system by reallocating labour to or from other resource-based agricultural activities, such as fuelwood collection, hunting and home-garden husbandry, our policy prescriptions may be more limited.

Finally, given the liberalization thrust in today's Mexico, an open economy case underpins the model. The results from the model are largely based on the parameters describing the system at work in the case stuy. Other studies that rely on simulations under similar agroecological contexts, albeit with differing parameters, would be helpful to check the robustness of the predictions of the effects of liberalization policies and their counteracting domestic policy interventions.

8. Appendix: Optimal dynamic rules for the use of soil and labour (PB)

The equation of motion [4]

N(t), the nitrogen stock in the soil is expressed as a non-linear function of *B(t),* scaled by a transformation agronomic parameter and linearly by an index expressing tree composition:

$$N\,(t) = v \ln\,[B(t)] + \sigma \qquad [A1]$$

The relationship between the motion of soil fertility in the farm and biomass felled in the farm plot is given by:

$$\dot{S} = \frac{v}{N}\,\frac{\dot{B}\,(t)}{B\,(t)} \qquad [A2]$$

where $\overline{N}$ is the carrying capacity of *N (t)*. Following López (1997), the dynamics of the fallow biomass on the average plot at the instant being cleared is expressed as

$$\dot{B}\,(t) = \gamma - \frac{S_{i=1}^{n}\,A\,(t)}{\overline{A}}\;B\,(t) \qquad [A3]$$

where *n* is the number of *SaB* households in the community, and $\overline{A}$ represents the total land area both fallowed and already in crop production. $\dot{B}\,(t)$ on fallow land increases by the constant natural growth: γ, but declines through conversion of forested to cultivated land, $[\sum_{i=1}^{n} A/\overline{A}]\,B\,(t)$. Inverting [A1] to obtain *B*, combining the result with [A2] and [A3] and assuming that all households in the village are identical (in terms of technology and preferences), yields the equation of motion [4].

The optimal farm labour path

The optimal path for labour allocation is derived by solving the current value Hamiltonian:

$$\widetilde{H}\,[S\,(t), L\,(t), \mu\,(t)] = U\,[m\,(t)] + \mu\,(t)\,\lambda\,[\gamma\,e^{-1/B\,(t)} - \Phi\,A\,(t)] \qquad [A4]$$

where μ(t) is the shadow value of *S (t)*. From the maximum principle it follows that the optimal labour path is:

$$\dot{L} = \frac{\lambda\Phi f_S - [r + \gamma e{-}1/^{B}]\, R}{\frac{\theta}{b/g} R^2 - R_L}$$

where f_S is the marginal product of soil fertility, R is the marginal net private return to on-farm labour, R_L is its first derivative with respect to L, and θ is the the marginal elasticity of staple *(m)* consumption.

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