Integrated Policy Options for Land Conservation and Rural Poverty Alleviation: A System-Dynamics Approach

Roberto Martinez-Espineira
Department of Economics
St Francis Xavier University (Canada)

Unai PASCUAL
School of Economics Studies
University of Manchester (UK)

January 2003

Abstract

The goal of soil fertility conservation in fragile and low-input agro-ecological systems often competes with other social goals, such as the maintenance of acceptable income levels. This paper explores such optimal policy options. The focus is on finding the correct instrument(s) to achieve the sustainable productive potential of the natural resource base while maintaining farmers' income levels above some pre-specified socially acceptable threshold. A system-dynamics approach is used to evaluate various price and wage policies in the context of a farming community operating under a common property land system and that is well integrated with the non-farm sector. The model considers endogenous exit-entry decisions by the households, from-and-to the farming community. This characteristics have been identified in rural areas of the Yucatán, Mexico, from where the data have been collected and used here to generate the numerical analyses.

Acknowledgements: *We owe thanks to Edward Barbier, Erwin Bulte and Charles Perrings for helpful comments on related previous drafts.*

1 Introduction

There is a growing corpus of descriptive accounts of land degradation in rural areas of developing economies, alongside numerous analyses of the economic causes of degradation in traditional agro-ecosystems. However, most modelling attempts to shed further light into the behavioral objectives and constraints behind land use strategies lack enough insight about farm households on- and off-farm labour diversification choices. This is surprising, since, in the eve of increasing market integration in traditional rural economies, even slight changes in the productivity of farming or off-farm wage rates constitute important drivers of labour allocation and consequently of land use decisions.

In an attempt to look at the sensitiveness of labour diversification strategies upon optimal use of land resources, this paper presents a bioeconomic modelling framework in which farm households' on- and off-farm labour use decisions are intrinsically interdependent with the quality state of the common pool agricultural land resource. More specifically, the focus is on a slash-and-burn natural forest-dependent agro-ecosystem similar to those that can be found in settled communities in developing rural economies. Farm households' decisions in these common property land tenure systems are often mediated by a large number of interrelated factors such as the existing off-farm labour opportunities, output-input prices, the productive state of the agricultural resource base, and even endogenous population changes.

This large number of feedback effects recommends the use of a system-dynamics approach. This paper presents an empirical framework to model these dynamic interactions based on field data from Yucatán (Mexico) and the bioeconomic theoretical model proposed by Pascual and Barbier (2001b), PB henceforth, and Pascual (2002). One innovative contribution of the present work is that the farming households' *privately optimal* entry-exit choices to-and-from the farming community is incorporated into the structure of the model. This makes it possible to simulate the effects of endogenous population adjustments to various economy-wide policies. This, in turn, permits the evaluation the usefulness of Neo-Malthusian theories of the relationship between land degradation and population dynamics. Another insight offered by this paper is the evaluation of the potential of several anti-poverty policies. Since peasant economies usually have very limited access to financial markets and to credit at competitive rates, farmers need to plan their livelihood strategies with an imperative constraint in mind. In this sense, the subsidiary role of the government would be to create the conditions for peasants to carry out their income-generating activities in such a way that their current income remains above a critical income threshold defined by 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. Furthermore, we argue that this control variable can be altered not only through policy intervention, but also through optimal community and household-level farming entry-exit decisions.

The paper proceeds as follows. The next section offers a mini-review of models of land degradation in slash-and-burn forest systems. Section 3 outlines the modelling framework with and without government intervention, 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 Section 5. The last section concludes by recapitulating and discussing the potential of government intervention to sustain farmers' income above the poverty limit and how it affects the socio-demografic and ecological dimensions of the community.

2 Land degradation models in slash-and-burn agroecosystems

Essentially, slash-and-burn (SAB henceforth), 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 topsoil 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 begun anew.

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 forest-land area to achieve a minimum crop output. This idea is Neo-Malthusian in inspiration and is popular in the agro-ecology literature (Sánchez, 1996). However, there have been few attempts to include a peasant behavioral component and market constraints to shed additional light to the fallow crisis problem (Dvorak, 1992; Albers and Goldbach, 2000; Pascual, 2002).

The bioeconomic models concerned with the analysis of the main drivers of land degradation under SAB has 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 arrived at by these SAB modeling traditions. The models take into account various ecological and economic signals (such as output prices) to evaluate the sensitivity of farmers' choice regarding the extent of cleared forested land and hence fallow periods and soil fertility. Furthermore, given our interest in an integrated on- and off-farm labour allocation decision mechanism, the role of *expected* off-farm wages dependent on household demographic characteristics, is also taken into account. Thus, not only market signals but also demographic characteristics feed into the model. An outline of the system-dynamic models follows. Last, the model recognizes that in the use of common property land resources, there are (a) intertemporal private costs of using 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 of village 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 Outlining the model

The starting point of the system-dynamics model is based on the optimal control model by PB. This is a separable agricultural household model, that spells out the socially optimal conditions for the allocation of labour (control variable) and, indirectly, of soil fertility (state variable), which are both inputs in crop production under SAB. In addition, the long-run effects of changing real wage rates and population densities are explicitly analyzed.

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.[1] This assumes that the representative household devotes a socially optimal level of labor to cultivation and forest exploitation during each period. 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 (through soil fertility) and economic (households' income) sustainability. In order to provide a context for the empirical system-dynamics model, a brief outline of PB is provided next.

It is assumed that n farm households[2] gain utility from consumption of an aggregate staple good (m) that can be either produced or purchased in the market. Therefore, 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:

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

where the discrete-time discount factor is given by $\rho = 1/(1+r)$, r being the periodic social discount rate. In addition, households face a budget and a soil fertility constraint:

- The budget constraint (in real terms and excluding the household's i subscript):

---

[1] The numerical simulation is built using the software VENSIM DSS.

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

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

where $H(t) = h[A(t), C(t), S(t)]$ represents the staple harvest function, the inputs being the area of new cleared land, A, *cropping* labour used in crop production on this land, C, and soil quality, S. Soil quality is included in the production function since, by 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) 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 $0 \leq g \leq 1$) 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]: $A(t) = \frac{gL(t)}{b}$. Field work research suggests that, on average, only 29% of the land cleared on the previous year is reused during a second cycle. This assumption is incorporated in the model.

- The soil fertility constraint is determined by the specific dynamics of soil quality in a slash-and-burn system, approximated in discrete time. Equation (2b) represents the equation of motion of soil fertility:

  $$\Delta S(t) \;=\; \lambda \left[\gamma\, e^{-1/B(t)} - \Phi(t)A(t)\right] \tag{2b}$$

  $S \equiv S(t+1) - S(t)$ 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.

---

[3] The present model allows for g to change through time, and depends on the average age of the household. Hence $A(t) = \frac{g(t)L(t)}{b}$.

Refer to the appendix for the derivation of the state equation and full notation of the model.

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 (1984), soil fertility is proxied by the nitrogen, $N(t)$, content in the topsoil, and it is assumed to be maintained through fallowing and without involving any activity such as 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:

- tree biomass during forest fallow prior to clearing (Trenbath, 1984), and
- 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.

PB use a continuous time and infinite time horizon framework to derive, through the maximum principle, an optimal rule for the allocation of labour (L) (see Appendix). Using this labour-allocation rule, and by departing from the infinite time horizon, our empirical model allows to find any endogenously determined time horizon $\bar{t}$. The latter time horizon is endogenous, since the model is not restricted to last any specified time. In fact, the time horizon is given by any of the following two basic scenarios:

- soil fertility has been totally depleted, and hence the ecological subsystem has collapsed from an ecological perspective, and
- the real income to 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 Yucatán[4] and it is well connected by road to the capital, Mérida, 55 km to the North-West of Yucatán.

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 1035 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 poverty levels are concerned, average income is \$4,665 (about US\$485), *per capita per annum* (pcpa) with 21% of households lying below the most extreme poverty line, determined by the expenditure needed to achieve a minimum nutritional requirement, i.e. \$2,376 pcpa or US\$ 258 pcpa (Pascual, 2002). This implies that the minimum acceptable dietary requirement, i.e. $\underline{m}$, for the representative household is just over 7,750 kg of maize/year.[5]

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 the off-farm labour market (Pascual, 2002). Besides the relative low imputed

---

[4] 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.

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

value of agricultural output, this is extremely important because of its role in food security.

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.

5 Three different scenarios

5.1 The socially optimal pattern of exploitation (Basic optimal model, BOM)

The first model 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 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. The assumptions 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) crop production is not ruled by any stochastic element, and (iv) financial markets exist that allow households to smooth consumption patterns intertemporally.

5.2 BOM results

A crucial element in the simulation is the specification of the production function. Here it is specified as a Cobb-Douglas: $H = h(\mathbf{x};\boldsymbol{\beta})\ e^{\mathbf{u}}$,where $\mathbf{x}$ is the vector (A, C, S) $\boldsymbol{\beta}$ are the elasticity parameters associated with each of the three inputs, and u is a standard white noise term. The production elasticities are, 0.98, 0.25 and 0.56 for A,C and S,respectively (Pascual, 2001)

Besides 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 mem-*

ber).[6] Under the optimal social behavior by the community, the model predicts that the system will last just under 11 years since soil quality 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 from that L first increases at a decreasing rate until 167 *dyh* (Figure 2). This implies that in the fourth year households begin to hire in farm labour, because all their disposable labour time is dedicated to farming. Hence, they completely leave the off-farm labour market in the 4^{th} year. Even if hiring in labour cuts into their cash budget with a negative average wage bill, this is compensated by crop production. In the sixth year also, production of maize begins to decline from almost 5 tons of maize by clearing approximately 6 hectares of forest-land. Yield levels are maximized in year 3 at 925 kg/ha, substantially more than in $t = 0$, (575 kg/ha) (table 1).

Assuming that household population is constant (apart from natural growth) during these 11 years, the income accrued by the households falls below the poverty line in the 4^{th} year (Figure 1). 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 the 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.

5.3 The intervened model (IM)

As explained above, smooth credit markets may not be enough 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 access to the forest resource by their members. In this case, at

---

[6] It is assumed that 6 hours/day are used in farming.

least in principle, the community could restrict access to the common pool resource by 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, in principle, by well designed extension services by the Government could increase the level of labour (versus land) intensification in farming. That is, the proportion of farming time spent not clearing forest land but rather cropping (including weeding, sowing, etc.) in the already cleared forest plot.[7]

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:

- the number of households that have the right to exploit the soil resource at time t=0 (n_0)[8]
- total farming time and its intensification level (g), and
- 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 undertake a mix of this *social* policy if it becomes profitable, that is, if the benefits to the community outweigh its costs.

5.4 The net benefits of the new system

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

$$\sum_{t=0}^{\overline{t^\star}} n_t^\star \rho^t P m^\star(t) - \sum_{t=0}^{\bar{t}} n_t \rho^t P m(t) \tag{3a}$$

---

[7] 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.

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

where, $\rho = \frac{1}{1+r}$ is the discount factor. There is the financial cost to the government, due to the subsidized wage payments[9] to the $n^\star$ remaining households:

$$n^\star \sum_{t=0}^{\overline{t^\star}} \rho^t (w^\star - w)[T - L^\star(t)] \text{ for any } t \text{ such that } [T - L^\star(t)] > 0 \tag{3b}$$

and

$$n^\star \sum_{t=0}^{\overline{t^\star}} \rho^t (w^\star - w)[-T + L^\star(t)] \text{ for any } t \text{ such that } [T - L^\star(t)] > 0 \tag{3c}$$

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

$$\widetilde{P} = \sum_{t=0}^{\overline{t^\star}} n_t^\star \rho^t P m^\star(t) - \sum_{t=0}^{\bar{t}} n_t \rho^t P m(t) - n^\star \sum_{t=0}^{\overline{t^\star}} |\rho^t (w^\star - w)(T - L^\star(t))| \tag{4}$$

where the $|\ |$ denotes *absolute value.* If the payoff is positive, policy would result in a Pareto improvement.[10]

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 $(n - n^\star)$ 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:

$$(n - n^\star) \sum_{t=0}^{\bar{t}} \rho^t \left[PH - w(L - T)|_{L-T>0}\right] \tag{5}$$

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

---

[9] Note that the subsidy applies to both off-farm and on-farm wages, which, under the assumption of frictionless markets, are assumed to be equal in long-run equilibirum.

[10] However, even if net social benefits are negative under the current policy from a 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!

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 dictate whether the policy is undertaken.

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

$$\begin{aligned} \widetilde{P} &= \sum_{t=0}^{\overline{t^\star}} n_t^\star \rho^t P m^\star(t) - \sum_{t=0}^{\bar{t}} n_t \rho^t P m(t) \\ &\quad - n^\star \sum_{t=0}^{\overline{t^\star}} \left| \rho^t (w^\star - w)(T - L^\star(t)) \right| \\ &\quad - (n - n^\star) \sum_{t=0}^{\bar{t}} \rho^t \left[PH - w(L - T)|_{L-T>0} \right] \end{aligned} \tag{6}$$

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 .

5.4.1 Model IM: The Government's maximization problem

The system has been numerically simulated to find the optimal 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:

- 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)
- the proportion of labour time used in clearing rather than cropping per area of cleared land, , i.e. g (from 0.1 to 0.99) and
- the number of households exploiting the system (with a minimum n^* of 50 households)[11]

---

[11] 50 households is an arbitrary number and used for expository reasons.

The optimization IM is conducted using as the objective the product of the *Pareto-improvement* payoff $\widetilde{P}$ as defined in Equations (4) and (6) 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's followed a maximization problem of the type:

$$\begin{array}{rrcl} & \max U' & = & \widetilde{P} \cdot \overline{t^\star} \\ s.t. & m(\overline{t^\star}) & > & \underline{m} \end{array}$$

5.5 IM Results

The results of the intervened model suggests that the shifting cultivation can be sustained for over 18 years by

- subsidizing the nominal wage rate w to increase it almost up to the prespecifed maximum: $w = \$24.76$/hour, from the current \$6.24/hour
- intensifying the farming of land already cleared (reducing g from 0.6 to the nearly minimum, i.e. $g = 10.41\%$, and
- reducing in t=0, the number of farming households to 366 (therefore relinquishing the land use rights by some 67 households, i.e. 83% of households keep their rights for farming in the common property land at t=0).

Table 2 and the Figure 1 show that the income of each of the households left in the milpa system[12] is substantially increased by the regulatory policy relative to the base case.[13] 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 $t = \overline{t^*}$, 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 (4), before compensation to evicted households. Even if

---

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

[13] 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.

the government financed the additional aggregate compensation payment of \$4.273 million to the 67 households evicted (as per Equation (5) in $t = 0$, the final net payoff would be \$123.26 million: the policy clearly results in a worthwhile Pareto improvement. This would be the case even if soil quality undergoes a steady decline (Figure 3).

5.6 IMEE: Model dynamics with household entry-exit possibility

In the model above, the social planner chooses the optimal labour allocation between the on- and off-farm sectors. However, the fact that incumbent households could exit (or new ones enter) the SAB system altogether was not considered. Another possibility would be to still consider the role of the social planner or the community cohesion mechanisms in the community in dictating the rules for optimal labour allocation by farm households, but allowing households to decide whether to continue using family (and hired labour) in farming or instead abandon the SAB system and use all their labour endowment off-farm. Of course, the subsequent return to farming would be an option for any household. In this new situation, the households' private decision to participate in farming depends on weighing the marginal value product of labour in farming and the exogenous wage rate that the household could obtain in the off-farm sector. The actual nonlinear relationships[14] found during the field work that directly relate the expected marginal return to labor in the SAB and the proportion of households in the system is used in the model[15]. The higher the return, the lower the average of the youngest household remaining in the SAB, and the higher the proportion of *milperos*. This proportion, combined with the maximum number of potential *milperos* (1,035, which includes those that do not participate in SAB at t=0) is used to estimate the number of expected households partaking in the SAB system.

$$\begin{aligned} v &= f(VMPL) \\ \frac{\partial v}{\partial VMPL} &> 0 \end{aligned}$$

---

[14] These involve the age structure and the likelihood to leave the milpa system.

[15] The lookup feature of VENSIM DSS makes it possible to introduce this true relationship without the need to specify any mathematical relationship to approximate the real curve.

where v is the proportion of households in the system and $VMPL$ is the marginal value product of labour applied to farming.

In addition, households' off-farm wage rate is dependent on human capital, which is proxied by age. In Yucatán, age plays an important role in the determination of off-farm wage rates (Pascual and Barbier, 2001a). Therefore, the model uses the average expected off-farm wage rate that can be obtained by the household dependent on its age structure. The estimated equation for the expected off-farm wage is given in Pascual (2002) which in turn follows the Todaro's formation wage idea, that is, the expected wage rate of the migrant (to the off-farm sector) is given by the interaction between the off-farm wage rate and the probability of finding a job:

$$E(W_o) = f(x) \Pr[f(x) > w^*] \tag{7a}$$

where $E(W_o)$ is the expected off-farm wage rate, $f(x)$ is a function that relates the off-farm wage rate with the household's average age (x) and $\Pr[f(x) > w^*]$ is a probability function for off-farm labour participation: the household supplies labour off-farm only if the potentially realized off-farm wage rate is higher than the shadow wage rate (marginal value product of labour in farming, $VMPL$). [16]

Finally, in this model g varies with the average age in the community, since the field work provides an estimation of the relationship between the age of the household and the proportion of farm labor devoted to clearing forest land.

The optimization problem implied the identification of the price level that would result in the maximum number of years that the system could be sustained with income over the absolute poverty line. That is, the following problem was solved:

$$\max_P \overline{t^\star} \tag{8}$$

$$s.t. \qquad m(\overline{t^\star}) > \underline{m}$$

5.7 IMEE results: The effect of price policies on the SAB system with entry-exit possibilities

A common concern when modelling the causes of land degradation using farm household models is about the output induced land degradation effect

---

[16] The wage-age relationship is given by $w_o|_{\Pr[f(x)>w^*]=1} = f(x) = 11.11 - 0.13x$ and the average $\Pr[f(x) > w^*]$ for farmers in the community is 0.25 (Pascual, 2002).

of input-output policy changes This concern is also present in PB, who find that in the steady state, a change in the staple unit price induces farmers to supply farm labour, which affects soil fertility in the community. The present model also looks at the effect of a price change, but unlike PB, it does so outside the steady state.

In Mexico, it is predicted that by 2008 the producer price of maize will decline up to 50% due to import liberalizations following the closing of the NAFTA agreement (Levy and van Wijnbergen, 1992). The potential effect on small farmers welfare due to the expected fall in maize prices is expected to be bleak (Levy and van Wijnbergen, 1992; Romero 1998).[17] Concerning the effect of the fall in price on land degradation by small farmers, predictions differ. Barbier and Burgess (1996) predict a higher level of deforestation in similar systems, given the higher expected migration to the forest frontier as a result of falling real wage rates (due to increase in nominal prices). In stark contrast, Deininger and Minten (1999) are more optimistic, because they expect a long-run fall in rural poverty as a consequence of economic growth boosted from trade liberalization. This in turn, they contend, will reduce deforestation rates. The debate about the effect of falling output prices on welfare and land degradation by small farm households thus remains open.

The optimal fall in prices to maintain the remaining older households out of absolute poverty would be from the current \$1.5/kg to \$0.63/kg, a 68% reduction in the nominal unitary output price of maize (Table 3). This fall would allow the remaining households to subsist within the SAB subsystem by the whole time horizon (50 years). Further, as can be seen in Figure 1, the average real income is well above the absolute poverty line. It would be $11,500$ kg, which is 50% higher than the minimum required for subsistence. This significant

increase in real income is explained by the dynamics of the off-farm wage bill, since crop output shows a rapid decline due to an steady decline in on-farm labour allocation (Figure 7).

Thus, our simulations show that, under the optimal price cut, both income levels by SAB farmers and soil fertility will increase. Of course, by discontinuing the producer-price subsidy, the government's treasury would benefit too.

The fact that a reduction in the price of the main commodity sold by

---

[17] They predict that, as a result of full maize price liberalization, efficiency in the allocation of resources in maize production will increase, which in turn will create higher rural unemployment, a decrease in wage rates, implying that rural poverty is expected to deepen.

the milpa farmers actually increases their welfare would, in any case, be consistent with the standard theory, once we consider that farmers in the model consume mainly maize too. The combination of substitution and income effects of the price fall and the entry-exit dynamics explain this result.

The BOM predicts that without any policy intervention, both the ecological and economic systems will collapse in a decade. $IMEE$ finds out the optimal fall in maize price that can stretch the time horizon with real income above the poverty line. This optimized fall in prices is expected to have a positive effect on soil fertility, in accordance with the theoretical long-run prediction by Pascual (2002). A closer look at the simulation results, indicates that soil fertility will not decline at any t, ($S = 0.50$), and that is practically stable (Figure 3).

The stability of soil fertility during the 50 years, is due to a steady abandonment of SAB practices by younger households. These decide to supply all their available labour time off-farm, and makes the remaining farmers in the community to optimally substitute some off-farm labour for on-farm labour. Indeed, compared to the *no price-policy scenario,* it is expected that: the number of households will decline dramatically over time, from 118 to 56, and where the exit from the milpa system starts with the youngest households and is followed by the relatively older households (Figure 6). In addition, the remaining 56 households would supply a significantly lower number of hours/year to farming. As shown in the diagram, the mean labour input in farming will fall by around 90% (Figure 2).

6 Discussion and conclusion

Most theoretical studies on the economics of shifting cultivation 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 analyse the effect on the dynamics of soil fertility.

This paper has provided various insights associated with policy options to maintain the productive potential of a typical tropical slash-and-burn system of the Americas. 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. Further, this is imperative since farmers' most important capital stock is related to the natural subsystem. In addition, governments need to find the right policy instruments in order not to negatively affect poor farm households' income levels. This paper has simulated with real biophysical and economic data, various of such policy options.

The analysis has been based on a system-dynamic model 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, such as prices or wages, we have presented a numerical bioeconomic system-dynamic model in which farm households' on- and off-farm labour use decisions are intrinsically interdependent.

The system is assumed to be managed efficiently, so the choice of labor per household devoted to milpa cultivation is socially optimal, given the off-farm wage conditions, the way in which the households distribute their farm labor, and, also very importantly, given the number of households in the system. It has been shown 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 even when managed under the constraint of a fixed number of households could be corrected if flexibility was introduced in terms of access to the system. Social welfare could be improved if an appropriate mechanism for compensating the evicted households were in place. The model has also shown that reducing output prices may be a good policy solution in order to both sustain the productive potential of the agro-ecosystem and increase households' income levels both in the short and longer run.

This very stylized system-dynamic model contributes to the understanding of the role of labour and soil allocation in shifting cultivation. But it is important that the assumptions of the model are acknowledged when interpreting the results. For instance, it has been 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. However, in the case of poor households, this may not be problem is not significant in the area of study since other resource-based activities rather than milpa take a small proportion of total disposable time. However, the case of richer households may be more problematic since the rich are often associated with a higher amount of discretionary time for pure leisure.

In addition, although the open economy case is consistent with the long-run scenario most agro-ecosystems in the developing world do not show either full or empty food and labour markets; instead, some level of friction is often the norm rather than the exception. This analysis is useful as an approximation to economies where the competitiveness of markets is high, and hence generalization of the results of the model to areas with high transaction costs in the food and labour market ought to be done with due caution. Lastly, it is recognized that due to potential relevance of aspects such as intra-year seasonality and risk in tropical agro-ecosystems, future developments of this model would need to relax the deterministic assumption.

7 Appendix: Optimal dynamic rules for the use of soil and labour (Pascual and Barbier, 2001b)

The equation of motion (2b):

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

$$\mathrm{N}(t) \, = \, v \ln[B(t)] + \sigma \tag{A1}$$

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

$$\dot{S} = \frac{v}{\overline{\overline{N}}} \frac{\dot{B}(t)}{B(t)} \tag{A2}$$

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

$$\dot{B}(t) = \gamma - \frac{\sum_{i=1}^{n} A(t)}{\overline{A}} B(t) \tag{A3}$$

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 (2b).

The optimal farm labour path:

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

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

where $\mu(t)$ is the shadow value of $S(t)$ From the maximum principle it follows that the optimal labour path is:

$$\dot{L} = \frac{\lambda\Phi\, f_S \;-\; \left[r + \gamma\, e^{-1/B}\right]\; R}{\frac{\theta}{b/g}\, R^2 \;-\; R_L} \tag{A5}$$

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.

References

Ahuja, V. (1998). Land degradation, agricultural productivity and common property: Evidence from Côte d'Ivoire. *Environment and Development Economics 3*, 7–34.

Albers, H. J. and N. Goldbach (2000). Irreversible ecosystem change, species competition and shifting cultivation. *Resource and Energy Economics 22*, 261–280.

Barbier, E. B. and J. C. Burgess (1996). Economic analysis of deforestation in Mexico. *Environment and Development Economics 1*, 203–293.

Barrett, S. (1991). Optimal soil conservation and the reform of agricultural pricing policies. *Journal of Development Economics 36*, 167–187.

Benjamin, D. (1992). Household composition, labor markets, and labor demand: Testing for separation in agricultural household models. *Econometrica 60*(2), 287–322.

Deininger, K. W. and B. Minten (1999). Poverty, policies and deforestation: The case of Mexico. *Economic Development and Cultural Change 47*(2), 313–344.

Dvorak, K. A. (1992). Resource management by West African farmers and the economics of shifting cultivation. *American Journal of Agricultural Economics 74*(3), 809–815.

Ehui, S. K., T. W. Hertel, and P. V. Preckel (1990). Forest resource, depletion, soil dynamics, and agricultural productivity in the tropics. *Jounal of Environmental Economics and Management 18*, 136–154.

Holden, S. T. (1993). The potential of agroforestry in the high rainfall areas of Zambia: A peasant programming model approach. *Agroforestry systems 24*, 39–55.

Kleinman, P. J. A., D. Pimentel, and R. B. Bryant (1995). The ecological sustainability of slash and burn agriculture. *Agriculture Ecosystems and Environment 52*, 235–249.

Krautkraemer, J. (1994). Population growth, soil fertility, and agricultural intensification. *Journal of Development Economics 44*, 403–428.

Larson, B. A. and D. W. Bromley (1990). Property rights, externalities, and resource degradation; locating the tragedy. *Journal of Development Economics 33*, 235–262.

Levy, S. and S. van Wijnbergen (1992). Maize and the free trade agreement between Mexico and the United States. *The World Bank Economic Review 6*(3), 481–502.

López, R. (1997). Environmental externalities in traditional agriculture and the impact of trade liberalization: the case of Ghana. *Journal of Development Economics 53*, 17–39.

López, R. (1998). The tragedy of the commons in Côte d'Ivoire agriculture: Empirical evidence and implications for evaluating trade policies. *The World Bank Economic Review 12*(1), 105–131.

Mizrahi, A., J. Ramos, and J. Jiménez (1997). Composition, structure, and management potential of secondary dry tropical vegetation in two abandoned henequen plantations of Yucatán, Mexico. *Forest Ecology and Management 96*, 273–282.

Nye, P. H. and D. J. Greenland (1960). *The Soil under Shifting Cultivation.* Commonwealth Bureau of Soils Technical Communication No 51. U.K.: Commonwealth Agricultural Bureaux.

Pascual, U. (2001). Soil degradation and technical efficiency in shifting cultivation: Applying stochastic production frontier to agriculture in Yucatan (Mexico). Discussion Paper N. 116, School of Economic Studies, University of Manchester.

Pascual, U. (2002). *Modelling Labour Supply and Soil Quality in Shifting Cultivation Agriculture.* Ph. D. thesis, Envronment Department. University of York, UK.

Pascual, U. and E. Barbier (2001a). Determinants of labour supply by shifting cultivation households: The effect of land quality and poverty. Paper prepared for the 11th annual conference of the European Environmental and Resource Economists (EAERE). Southampton (UK).

Pascual, U. and E. Barbier (2001b). A model of optimal labour and soil use with shifting cultivation. Fondazione Eni Enrico Mattei. (FEEM), Note di Lavoro Series: NRM 83:.

Romero, J. (1998). Mexican agriculture: Distribution and efficiency effects of eliminating price distortions. *The World Economy 21*(5), 659–674.

Salehi-Isfahani, D. (1988). Technology and preferences in the Boserup model of agricultural growth. *Journal of Development Economics 28*, 175–191.

Sanchez, P. (1996). Introduction. *Agriculture, Ecosystems and Environment 58*(1), 1–2.

Trenbath, B. (1984). Decline of soil fertility and the collapse of shifting cultivation systems under intensification. In A. Chadwick and S. Sutton (Eds.), *The Leeds Symposium*, pp. 279–292. Leeds, U.K.: Leeds Philosophical and Literary Society.

Walker, R. (1999). The structure of uncultivated wilderness: Land use beyond the extensive margin. *Journal of Regional Science 39*(2), 387–410.

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 $)	-23.94	7,732	-7,837	19,644
Soil quality (from 0 to 1)	0.29	0.1527	0	0.4943
Fallow time (years)	6.706	5.809	0	16.11
Real income (kg of maize)	6,379	4,764	-1,952	16,647
Maize harvest (kg)	3,478	1,269	0	4,892
Maize yield (maize kg/ha)	722	218.57	8.802	925.93
Plot area (ha)	5.10	1.663	0.8643	6.777
Number of households (n)	471.76	22.39	433	510.52
Off-farm wage ($/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.

Table 2: Summary of results Intervened Model IM

	IM			
Variables	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 3: Summary of results Intervened Model with Entry-Exit IMEE

	IMEE			
Variables	MEAN	ST DEV	MIN	MAX
Farm labour (hours/year)	76.95	153.91	7.78E^{-18}	638
Wage bill (in \$)	2,875	122.78	2,782	3,152
Soil quality	0.4984	0.0063	0.49	0.5101
Fallow time (years)	16.41	0.4575	15.81	17.26
Real income (kg maize)	11,520	295.7	11,307	12,149
Maize harvest (kg)	66.15	141.55	1.87E^{-18}	621.01
Maize yield (kg/ha)	322.01	191.83	185.76	760.73
Plot area (ha)	0.099	0.1981	1.00E^{-20}	0.8203
Number of households (n)	56.2	22.77	36.14	118.22
Proportion of L felling (g)	0.5627	n.a	n.a	n.a
Average age of household	61.66	1.932	56.93	62.99
Expected wage off farm	0.7835	0.0624	0.7404	0.9364
Maize price *(\$/kg)	0.63	n.a.	n.a.	n.a.

Table 4: Notation used

Variables	Description	Units
$v(t^{IMEE})$	the proportion of farming households	% (of 1,035)
$VMPL(t)$	marginal value product of farm labour	$ (Mex pesos)
$H(t)$	Harvest	kg maize/hh/yr
$S(t)$	Soil fertility index	Index (from 0 to 1)
t	Time period	years
$L(t)$	Farm labor	hours/hh yr
$m\ (t)$	real income	kg maize
$n(t)$	number of households in teh SAB system	
λ	Soil N transformation rate / max N	(scalar)
γ	natural growth of biomass	(scalar)
$B(t)$	forest biomass	ton/ha
$\Phi(t)$	Population density in community	hh/ha
$\overline{A}$	Total land area in the community	ha
$A(t)$	Felled forest-land area per household	ha
$N(t)$	Nitrogen nutrient stock	mg/gr soil
T	Household's disposable labour time	hours/year
$g(t^{IMEE})$	Proportion of L in felling forest trees	from 0 to 1
b	Intensity of felling trees	hours/ha
E	Non-farm labour real income transfer	kg
R	Marginal net private return to on-farm labour	
c	Real wage rate	kg/hour
$w(t^{IMEE})$	Nominal wage rate	$/hour
$x(t^{IMEE})$	Household average age	years
$\widetilde{P}(t)$	Government's payoff	$
v	Nitrogen transmormation rate (biomass to soil)	scalar
$\mu(t)$	Shadow value of soil fertility	kg

(t^{IMEE}) denotes variables that vary in time only under scenario IMEE

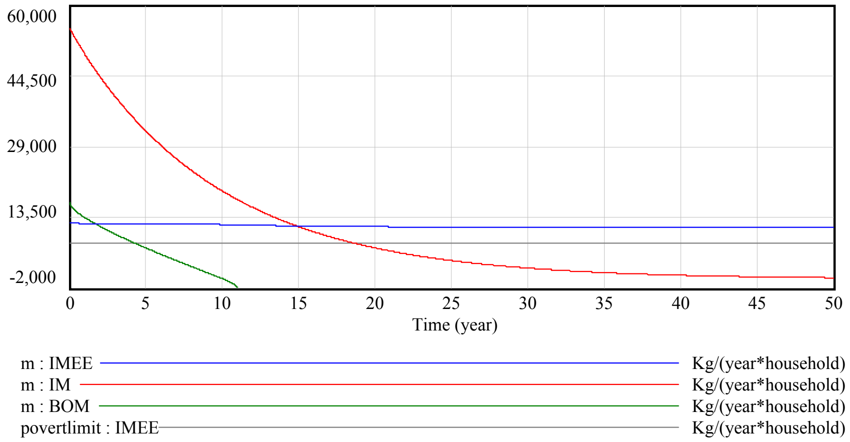

Figure 1: Income versus poverty limit, all models

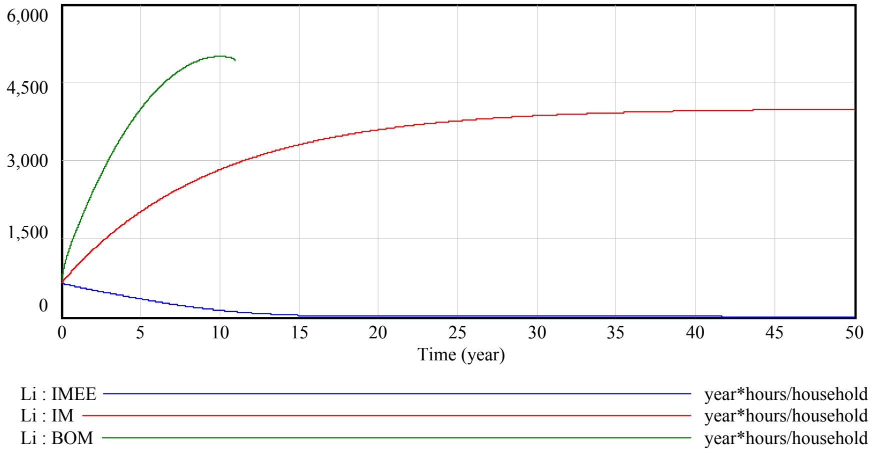

Figure 2: Labor, all models

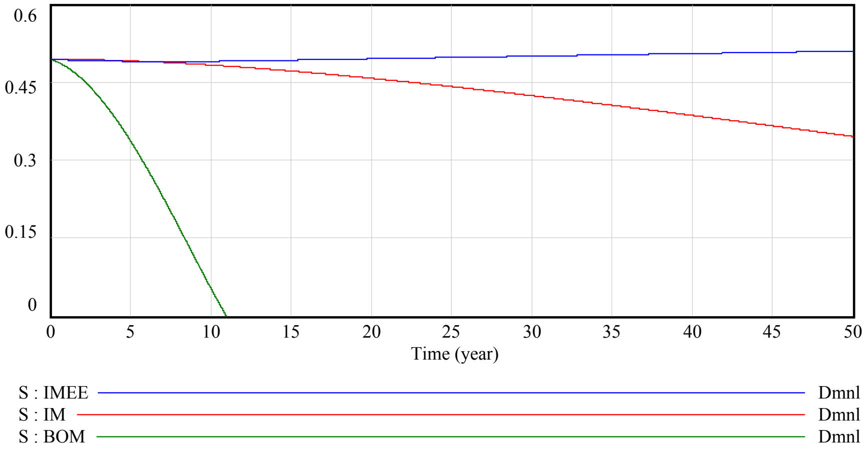

Figure 3: Soil quality, all models

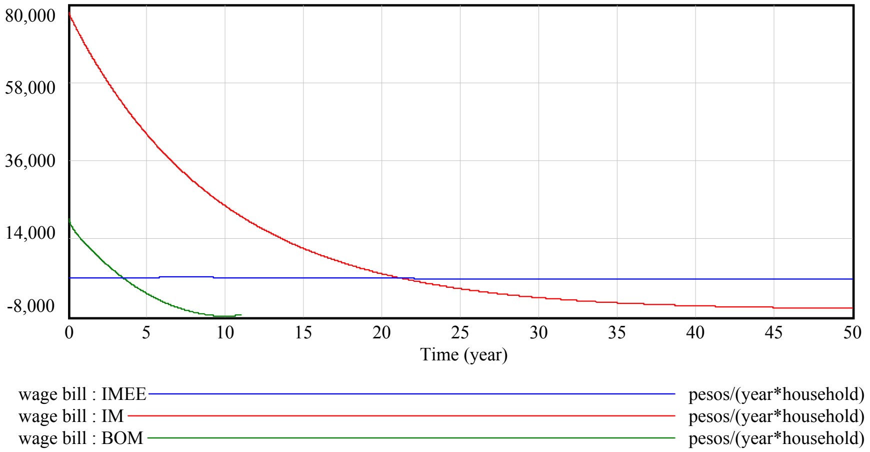

Figure 4: Wage bill, all models

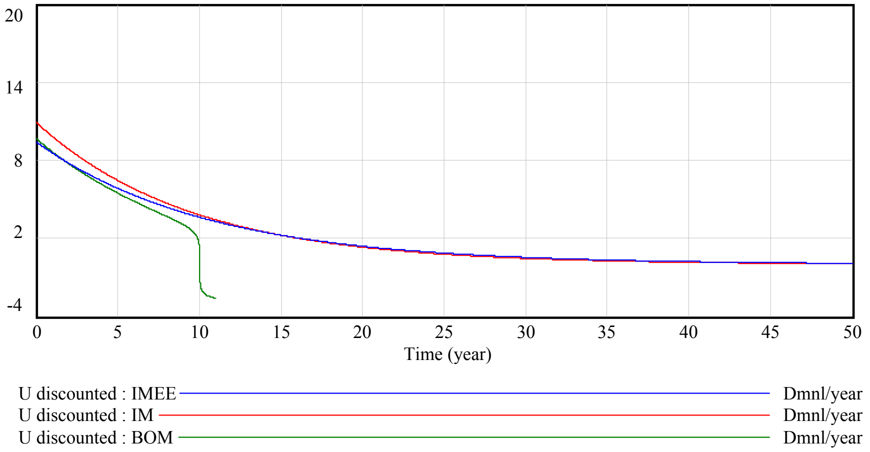

Figure 5: Discounted utility, all models

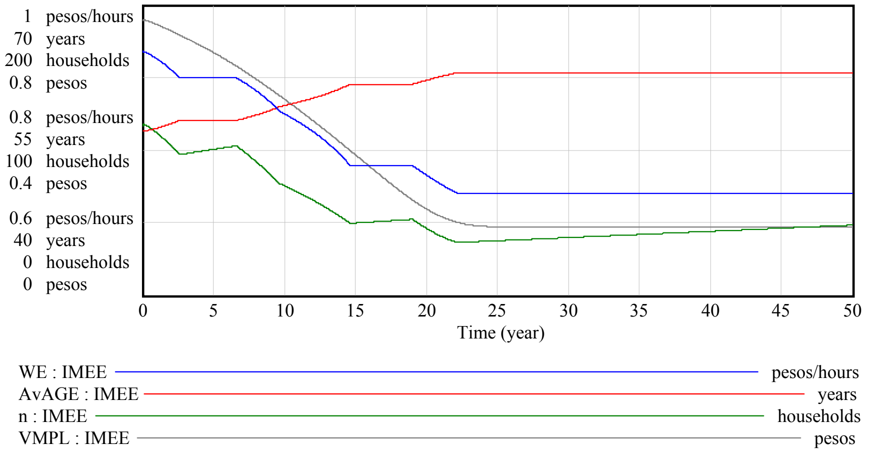

Figure 6: Average expected salary, Average household age, number of households and Value of the marginal product of labor, Model IMEE

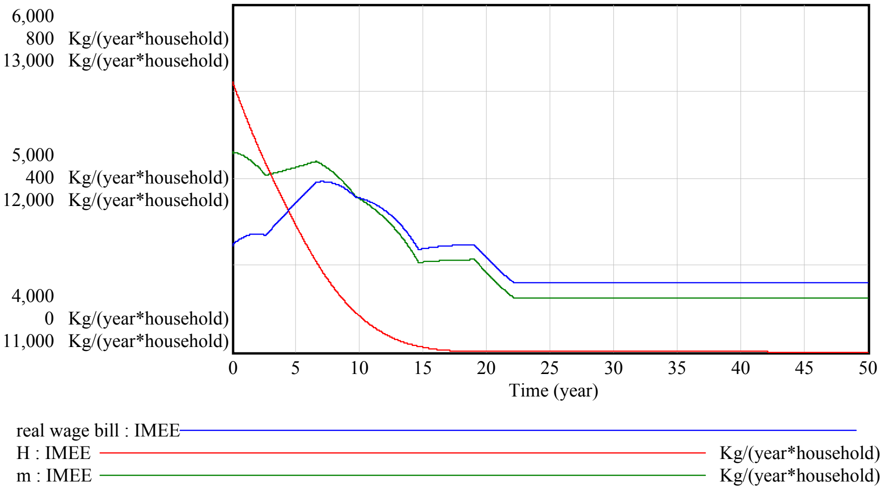

Figure 7: Real wage Bill, real income and harvest iunder $IMEE$.