Modelling PES in forest biodiversity conservation: predicting partial participation and additionality

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Abstract

This paper presents a static mathematical household opportunity cost model for the assessment of possible participation and additionality of a PES-programme aimed at forest biodiversity protection in developing countries. The opportunity cost model estimates an agricultural household's income from farming own land, non- and off-farm work and incorporates basic household characteristics (farm and household size, education level, present land-use distribution), land-use choice variables (crop production, livestock, forest, PES), farming effectiveness/productivity, employment possibilities and a set of key exogenous factors (e.g. average wages and produce prices). The opportunity cost model takes its point of departure in the general agricultural household economy theory and is further detailed based on in-depth case-studies of ongoing PES programmes in El Castillo (Nicaragua) and Maquenque (Costa Rica), both part of Rio San Juan watershed. The result is a general explanatory mathematical model that can estimate an agricultural household's economic incentive to participate in a PES programme to conserve forest, partially or wholly, as well as the additionality of the programme vís-a-vís the likely without-PES scenario land use. The participation model is tested on case study data and it is suggested how it may be applied for PES policy planning and evaluation purposes.

Key words: PES, forest protection, household model, opportunity costs, participation, additionality, policy design.

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1 INTRODUCTION

1.1 Background

The modest body of evidence on cause and effect of PES programmes originates predominantly from PES initiatives frequently being implemented without evaluation in mind (e.g. Ferraro 2009), i.e. with no baseline against which to measure impact and/or no simultaneous monitoring of a similar non-treatment group to weed out rival explanations for observed changes over time. This lack of counterfactual data poses a problem when attempting qualification and quantification of PES impacts, and likewise when trying to identify linkages between causes (PES or rival cause/explanation) and effects.

The lack of thorough, empirically based studies of PES impact is echoed by several researchers (e.g. Muridian et al., 2010; Wunder, 2007). Muridian et al. (2010) lament the consequence of this, i.e. a dominating theoretical approach to PES, making research less applicable in policy design and implementation. Pattanayak et al. (2010) presents a thorough review of the existing PES literature similarly raising a number of issues for further investigation, primarily the lack of impact evaluation and a need for quantitative causal analyses of PES effectiveness to guide future policy design. They also find little evaluation of programme additionality and argue for more *a priori* planning and design of PES-programmes to ensure that their effectiveness can be evaluated.

While existing ex-post studies of factors correlated with participation *do* provide reasons to suspect certain links to a number of household characteristics, they do however imply a larger risk of misinterpreting cause and effect relationships, and offer no information on additionality. This study is thus partly inspired by Zbinden & Lee (2005), who report on such correlations from an extensive multi-nominal statistical analysis of three forest protection, reforestation and sustainable management programmes in Costa Rica. They find, statistically, that factors associated with farming systems, household characteristics, farm sizes, and information access significantly influence a household's decision to participate in PES-programmes. Some important aspects, however, receive less attention by Zbinden and Lee (2005). These include the possibility of partial enrolment (will participants enrol 100%, 50% or less of eligible forest) in PES, socio-economic and land use distribution impacts of PES introduction and consequently additionality.

Partial enrolment invokes the issue of possible on-farm slippage as a consequence of PES introduction, as shown by Alix-Garcia et al. (2010), who provide a theoretical analysis of this issue. While providing insights into potential consequences of PES introduction and substantiating the risk of on-farm slippage under certain conditions, the strictly theoretical approach of Alix-Garcia et al. (2010) does however not provide any clear link to empirical reality, i.e. how policy makers may go about determining if the potential risk is real or not and the quantitative extent of this possible risk.

To bridge the very empirically founded, statistically derived, but non-causal indications presented by Zbinden & Lee (2005) on one side and on the other the strictly theoretical simulation analysis presented by Alix-Garcia et al. (2010), we have here set out to investigate such causal links and derive an empirically grounded and explanatory model that, based on case study data and findings, can predict conditioning factors for households' full or partial participation in a PES-programme as well as outcome in terms of economically prioritized land and labour use. In doing so, we hope to bring theoretical and practical PES research closer to one another for the benefit of future PES policy design.

The present study thus makes a contribution towards formalising and quantifying the links between basic household conditions (land, socio-economic), possible choices and land-use impacts given introduction of a PES-programme, facilitating policy planning that allows for rigorous impact measurement.

1.2 Problem formulation

It has proved difficult based on initial income/poverty categories alone to predict the degree of PES participation and impact (additionality) on livelihood strategies, income impact on poor and non-poor, and in terms of subsequent land use choices (environmental additionality and risk of on-farm leakage). Previous studies (Pagiola et al., 2005; Pagiola et al., 2008; Wunder, 2008; Høybye and Vinqvist (unpublished)) show few to no clear-cut tendencies based on the mere up-front poverty status or dominant income source (agriculture or paid off-/non-farm work), possibly because access, eligibility and self-selection has skewed PES participation before any impact can be observed.

Attempts at estimating participation has hitherto primarily been of the statistical 0/1 type, whereas our case studies show that it is indeed quite common that less than 100% of eligible forest area is enrolled. This suggests that opportunity costs are uneven across the hectares of a farm, and we would like our predictive model to be able to encompass this aspect. Likewise, foregone income is indeed a relevant indicator of economic benefit of PES participation, but is in an unconstrained form likely to overestimate the actual opportunity costs of participating, since family farm labour and capital are realistic constraints to expanding agricultural land. Difficulties in predicting participation and additionality, and particularly impact quantitatively, arise from the wide variety of trade-offs faced by households (HH) maximizing income under due consideration to i) HH assets and ii) contextual conditions, which act as fixed (in the short to medium term) constraints on HH behaviour. Nevertheless, literature on private information rent harvesting (e.g. Ferraro, 2008) and recent studies in Nicaragua (Høybye & Vinqvist, unpublished) support that HHs act in a rational manner to optimize their overall well-being, primarily via income maximization, and a rational relationship is thus assumed between asset bundles and livelihood strategies under due consideration of exogenous factors. Studies of these relationships have in other areas of research frequently taken the form of HH or farm income models, contrary to PES where a flat rate marginal income from one alternative (to PES) land use has typically been employed for all hectares of a farm. The point of departure is therefore a more detailed, instructive farm HH model, but modified to include PES, *five* land-use types (instead of one or two) and actual income sources, labour preferences and observed livelihood strategies, and key case specific contextual factors to examine causal links.

1.3 Research questions and response

In response to the above problem formulation, we wish to investigate, via case studies and HH income model analysis, the hierarchy of economic choices made by participants in order to identify which HH characteristics influence PES participation, and the subsequent socio-economic and environmental impacts of that participation. This leads to the following research questions:

1. How does participation in PES affect HH allocation of labour and land?
2. Which up-front HH and contextual characteristics are decisive for participation and additionality of PES?

To support the quantitative prediction of PES-participation and related impacts we formulate a mathematical explanatory model based on empirical data. The model revolves around labour, land-use and capital allocation.

Fieldwork was conducted in Nicaragua (El Castillo) and Costa Rica (Maquenque) to gain an understanding of household decision processes and hierarchies necessary for model development, and suggested that in this particular case at least a HH's choice of land use distribution (and use of available capital) primarily depends on the quantity and quality (e.g. education level) of the available labour resources, and secondarily on land endowment, since the latter was generally ample.

The following therefore first includes a description of the case study setting and data collection (section 2), followed by section 3 on the model development and components. This first includes a qualitative description of the HH's decision hierarchy for allocation of available labour (section 3.1), in order to maximize HH income, and how this depends on returns to the various labour uses. Section 3.2 next describes how a basic agricultural HH model is modified leading to the development of the proposed PES-participation model. The model is then used (section 3.3) to explore the causal links between HH labour, land and capital endowment and PES-programme participation, additionality and impacts. The results of the analysis are presented in section 4, discussed in section 5 and conclusions presented in section 6.

2 Study area and data collection

The PES group in El Castillo, Nicaragua, consists of 12 HHs (100% of participants), and the control group of 21 HHs from the same area, displaying similar socio-economic characteristics (Høybye & Vinqvist, unpublished). In Maquenque, Costa Rica (CR), the PES group (habitat protection only as in Nicaragua) consists of 54 HHs of whom only one lives on the farm and only 12 HHs use the farm for agricultural production. The remainder of the CR PES group participants keep the farm for mainly recreational and investment purposes. There are 21 participants in the Maquenque control group, of whom 9 use the farm for agriculture and 3 live on the farm. Only households with active agriculture are included in the following presentations, as the model is based on agricultural households only. The model is thus suitable for agricultural HHs and areas where such dominate only. All key HH data are presented in Annex B.

Following Thomas (2004), cited in Arriagada et al. (2009), an iterative and explanatory approach was adopted based on both open-ended and structured field interviews, and follow-up interviews were made to clarify issues and gather additional data. The basic structure of the HH income model presented is a result of the initial interviews with farmers. Questionnaires were then developed to provide the data and information that would be necessary to quantify (and explain) the selected key variables and parameters and ultimately estimate the income and livelihood dynamics of agricultural HHs. Household interviews and resulting data were organised in three sections with a mix of quantitative and qualitative results: i) basic farm and HH data; ii) current land use and farming practice; and iii) HH strategy and PES-related information. This provided primary data for model use: land-use distribution, HH labour resources, and income and input breakdown in main activities: i) non-farm work; ii) off-farm (farm) work; iii) PES; iv) crop production; and v) livestock production, including prices, production and labour input.

3 Methodology and model development

The approach chosen is based on standard agricultural HH models developed e.g. by Singh et al. (1986) and Howitt (2005). This is modified according to the HH labour decision hierarchy presented below in Section 3.1, since it is ultimately the allocation of labour for on-farm work, which determines the maximum agricultural area the HH can hope to cultivate and hence the risk of competition between forest and agricultural land on the farm. This modification is included, since our main interest is additionality and the possible conversion of forest to agriculture. For this reason, it is advantageous to first develop a labour sub-model that can give a coherent estimate of a HH's labour allocation preferences and on-farm labour resource. Labour allocation was chosen as the point of entry, since farm size in the case study area was generally not a constraint compared to labour to farm that land. Capital, however, was a constraint due to lack of credit institutions and widespread poverty. Land renting was likewise uncommon, and hence omitted as a specific option.

The overall model development approach (see Figure 1) is thus to: i) formulate an income maximising sub-model estimating the allocation of labour resources in a HH according to education level and assets (model part 1); ii) use availability of HH labour and capital resources to determine whether there is a significant risk of direct competition between existing forest area and agricultural production (model part 2); and iii) having obtained an estimate of the land-use competition risk, convert this risk and the various relevant opportunity cost ratios to an estimate of the expected degree of participation and additionality of a PES programme (model part 3). An overview of the variables and parameters used in the HH income model are given in Annex A.

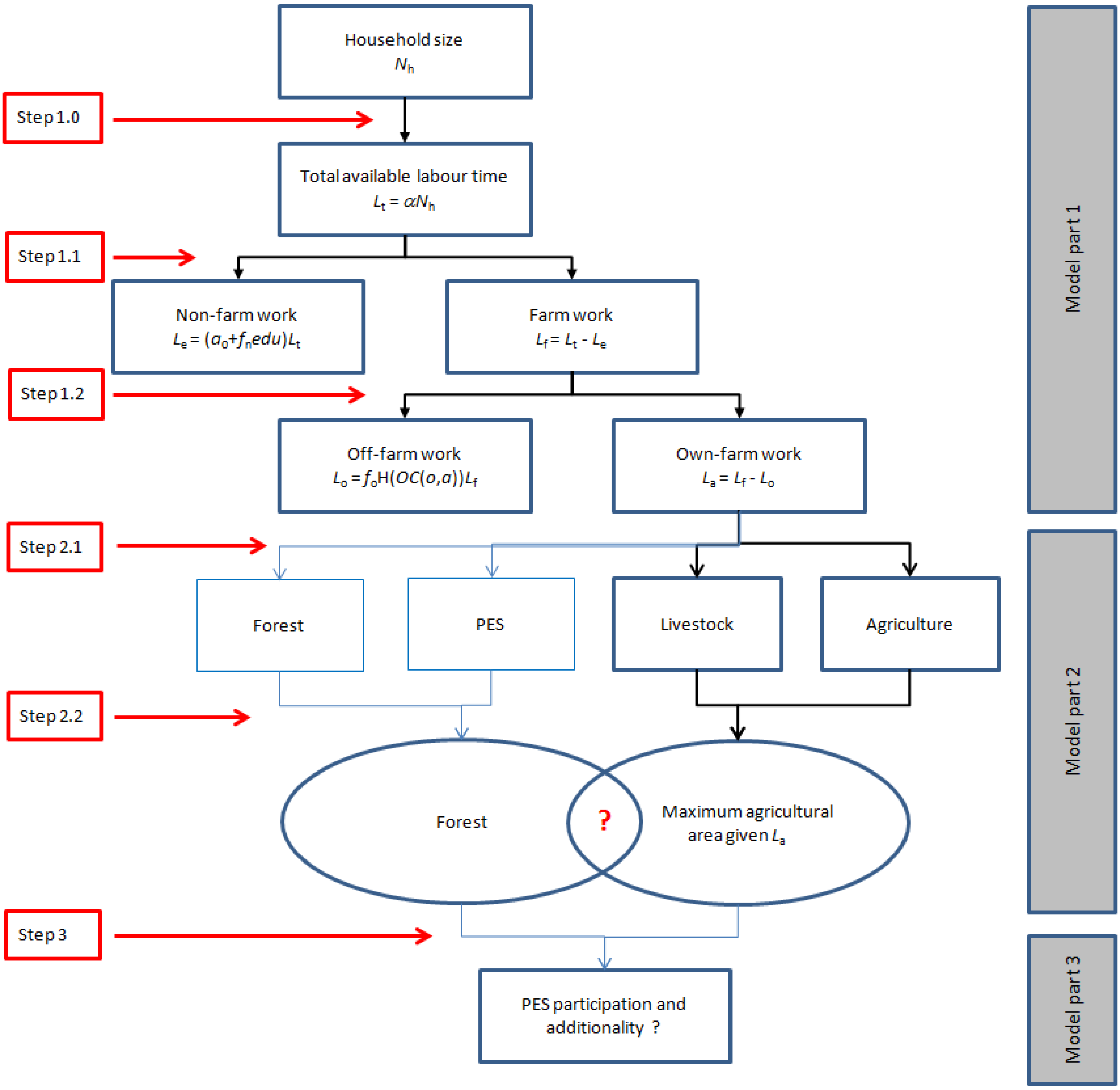

Figure 1: Model overview

3.1 HH labour decision hierarchy - Model part 1

Step 1.0 – Basic household composition

Based on analysis of case study data from Costa Rica and Nicaragua a relatively clear hierarchy of economic labour allocation preferences appeared, ranking allocation of total available labour time (L_t) according to return to various possible labour investments. In the present study, respondents provided information about HH size, age distribution and use of time, which made it possible to obtain reasonable and consistent estimates for allocation of labour resources. The below steps describe how households reported on the hierarchy of labour allocation decisions, the net input to which is L_t, the total available HH labour (number of full-time workers) based on HH size (N_h; number of persons) and modified by α_f, a proportionality factor related to age of household members:

$$L_t = \alpha_f N_h \tag{1}$$

Step 1.1: Non-farm work

In both El Castillo and Maquenque, it was evident from stated preferences that non-farm work (L_e) requiring a longer education, specific skills and/or capital investment (e.g. micro businesses) was preferred to any kind of farm work, whether on own farm (on-farm work, L_a) or on the property of others (off-farm work, L_o). Since salaries for non-farm work (average figures reported ~ 2,000 US$/year in Nicaragua and 7,000 US$/year in Costa Rica) was significantly higher than those for farm work (700 US$/year in Nicaragua and 2,900 US$/year in Costa Rica), HHs seek to maximize non-farm work. In the present study, information about education level of all HH members was collected. Based on the individual education levels, we have established a composite HH education level indicator as a weighted average as follows:

$$edu = \frac{1}{Nh}\sum_{i=1}^{Nh} n_i \frac{EDU_i}{7} \tag{2}$$

where n_i is HH member no i and EDU_i is the highest educational level of that person, ranging from 0 (no education) to 7 (university degree). Hence, *edu* is a number between 0 (no education at all) and 1 (all HH members have university degree) that characterizes the HH's education level.

It is also suspected that although positions for educated persons are not the only attractive non-farm work, the frequency of non-farm work is nevertheless related to the level of formal education (*edu*) in a target group. This is confirmed by e.g. Zbinden & Lee (2005), Hernandez, Reardon and Guan (2010) and Isgut, 2004). The actual level of non-farm work is likewise related to availability of work (f_n). If no data is available, the simplest estimate of HH non-farm work is thus a linear function of education level, assuming the maximum employment frequency is f_n, and with a basic constant possibility, a_0, of obtaining non-farm income even without education (e.g. self-employment):

$$\frac{L_e}{L_t} = a_0 + f_n edu \tag{3}$$

Having estimated the amount of labour time that is likely allocated to non-farm work, the remaining labour time that can be used for farm work (L_f), on own farm or off-farm, is calculated as:

$$L_f = L_t - L_e = \alpha_f N_h \left(1 - \left(a_0 + f_n edu\right)\right) \qquad (4)$$

Step 1.2: On- or off-farm farm work?

In the Nicaraguan case taking paid work on other people's farms, i.e. off-farm labour (L_o), was for many HHs more attractive than working their own farm (L_a). Preference for one or the other was decided by the relationship between wages (w) and availability of off-farm work (f_o) on one side and the returns generated by investing that same time in farming one's own farm instead. This translates to the relationship between the per-capita marginal income from off-farm work (MIC_o) versus on-farm work (MIC_a), where $MIC_o = f_o w$ and MIC_a is the higher of either livestock-related marginal income per capita $MIC_l = p_l y_l e_l$ or crop-related marginal income per capita $MIC_c = p_c y_c e_c$. Prices (p; US$/hectare or head), yield (y; kg or heads per hectare) and effectiveness (e; man-hours required per head or hectare per year) compose marginal income per capita and are based on respondent information, crosschecked with local key informants and FAO statistics (FAO undated).

In practice this meant that farmers with low agricultural yields and/or low production effectiveness were more likely to prefer paid off-farm work. This was reported as depending on availability of such work, but preference must play some part when considering that a certain distance may be unacceptable or render off-farm work unprofitable. Preference for leisure is indistinguishable from this, unfortunately, but given the poverty in the area the frequency of off-farm work (f_o) in practice most likely reflects local availability without, however, any attempt at quantifying 'local'. We have chosen to incorporate f_o as an exogenous variable, intended to approximate the likelihood of being able *and* willing to abandon own farm work and obtain paid off-farm work elsewhere.

The distribution of available farm labour thus depends on the per-capita opportunity cost ratio ($OC(o,a)$) between off-farm work ($f_o w$) and the maximum per-capita value of on-farm crop or livestock farm labour = $r_s \max(p_c y_c e_c, p_l y_l e_l)$:

$$L_o = f_o H\left(OC\left(o,a\right)\right) L_f \qquad (5)$$

where $H(x) = 0$ for $0 < x < 1$ and 1 otherwise. Mathematically, this particular rectangular function, H(x), is defined by the combination of two Heaviside step functions (Φ(x)):

$$H(x) = 1 - \left[\Phi(x) - \Phi(x-1)\right] \qquad (6)$$

If income from off-farm work is higher than the income one person can generate on own farm, off-farm labour is preferred, if off-farm work is to be found. By including steps 1.0 and 1.1 it then follows from the time conserving equation (7) that the HH labour available for own farm work can be summarized as:

$$L_a = L_f - L_o = \left(1 - f_o H\left(OC(o,a)\right)\right)\alpha_f N_h \left(1 - \left(a_0 + f_n edu\right)\right) \qquad (7)$$

3.2 HH land use decision hierarchy - Model part 2

Step 2.1: Land use decisions

Being able to estimate how much man-power will be dedicated to on-farm work, i.e. cultivating own farm, the next part of the model uses this input for maximization of total HH income given the simplified four active options of land use. The allowed forest use implies minimal labour input (set at zero), and as PES is habitat protection this land use/income option is likewise labour free. Actual labour-based land use decisions are thus reduced to a choice between cropping and livestock depending on the return to time and capital invested. If marginal income from cropping (MIA_c) is higher than marginal income from livestock (MIA_l), cropping is prioritized until a land, labour or capital constraint (price of converting forest to cropland) is reached. If MIA_l is higher than MIA_c, livestock rearing will be prioritized until a land, labour or capital constraint (price of converting forest to fenced pasture, cost of purchasing cattle) is reached.

In Høybye & Vinqvist (unpublished), a detailed and linearized standard agricultural income model was formulated based on case study data. This numerical income optimization model accounts for land use choices that includes five different land-uses with associated labour input requirements (albeit zero for fallow land, PES and forest) and is taken as point of departure for development of our analytical land-use distribution and participation model.

For calculation of MIAs (marginal incomes per area unit), an average of the five most common crops have been used for price (p_c), yield (y_c) and effectiveness of manpower (e_c) in cropping. For livestock, an average of reported price (p_l), density of cattle per hectare (D_c), yield, i.e. net growth of herd (y_c) and effectiveness of manpower input per head of cattle (e_l). Possible PES payments are included (labour free) at a price (p_p), as is average income (p_f) from standing forest (labour free) as reported by PES and control group respondents. The HH-specific agricultural parameters (y_c, e_c, y_l, e_l, D_l) have been estimated directly from case study data (data summary presented in Annex B), not involving any form of statistical fitting (Høybye & Vinqvist unpublished). Produce prices have been obtained from farmers' responses and checked against the FAO-STAT crop and livestock price database (FAO undated). The option of hiring labour (L_h) for work on own farm is included, although this was a rare occurrence in practice. Given these data, present land-use distribution (A_c^0, A_l^0), share of production sold (r_s) and labour market data, we can maximize HH income X_a from farm work and by doing so estimate the optimum land use distribution:

$$\max_{A_p, A_f, A_c, A_l, L_o, L_h} X_t = X_e + p_p A_p + p_f y_f A_f + r_s p_c y_c A_c + r_s p_l D_l y_l A_l + f_o w L_o - w L_h \qquad (8)$$

where A_p is area under PES contract, A_f is area under forest cover (not PES), A_c is crop area and A_l is livestock area (pasture). Two additional area uses have been included, namely fallow area (A_r) to reflect the shifting culture aspect of agriculture, and a minimum subsistence area (A_s) to reflect the prioritization of a basic area for subsistence by encountered HHs. Income from non-farm work, X_e, is added to the farm income to give the total HH income X_t.

The land (1-3), labour (4) and capital (5) constraints employed by the model are as follows:

1. $A_p + A_f + A_c + A_l + A_r = A_{tot}$

meaning total farm size is an absolute constraint on available land for income maximization.

2. $A_p + A_f \leq A_{of}$

meaning that forest enrolled under PES contract (A_p) plus remaining un-enrolled forest (A_f) cannot exceed the original, intact pre-PES forest in the farm.

3. $A_c + A_l \geq A_s$

meaning that the total farmed area must be at least as large as the area reported necessary for supporting a HH.

4. $L_c + L_l + L_o = \frac{1}{e_c} A_c + \frac{D_l}{e_l} A_l + L_o \leq L_t - L_e + L_h$

stipulating that you cannot farm more area than your manpower allows, rented or own.

5. $i_c(A_c - A_c^0) + i_l(A_l - A_l^0) \leq C \;\Rightarrow\; i_c A_c + i_l A_l \leq C + i_c A_c^0 + i_l A_l^0$

meaning that more capital has to be available than that required for conversion of forest to agriculture for such conversion to take place.

If the production functions in equation 8 are combined with the above constraints we can define the per hectare marginal income (*MIA*s) as:

$MIA_c = r_s p_c y_c - f_o w/e_c$

$MIA_l = r_s p_l y_l - D_l f_o w/e_l$

$MIA_c = p_f y_f$

$MIA_p = P_p$

Unit land conversion costs (i_c, i_l) and labour wages (w, w_n) have been estimated from information provided by the PES and control group respondents and corroborated by the local PES programme administrators.

Step 2.2: Assessing the degree of competition between farm land uses after introduction of PES

The decision to keep existing forest (A_{of}) depends on whether the HH experiences an agricultural land constraint: if HH assets (labour and capital) permit profitable expansion of the agricultural area, forest is in actual danger of being converted. First step, therefore, is to define the key land-use decision variable, A_d, which measures whether it over time would be likely, if economically profitable, that forest is converted to agricultural use:

$$A_d = A_{tot} - A_{of} - \phi A_a^{\max} \tag{9}$$

In eq. 9, $A_a^{\max}$ is the maximum area that can be expected to be utilized for agricultural production in the pursuit of income maximization, given the HH's production effectiveness and labour and capital constraints. The rotation factor $\phi > 1$ allows for the HH to leave part of the agricultural area as fallow area (40% is average in the Nicaragua PES-group => $\phi = 1.4$).$A_a^{\max}$ is thus crucial to evaluating the likelihood of deforestation, but requires careful calculation.

In the following, we will develop an analytical approximation to the optimization problem in eq. 8 assuming that: i) labour and capital are the main constraints when a HH seeks to maximize its total income, and ii) present (pre-PES) agricultural land-use $A_c^0 + A_l^0 \leq A_{tot} - A_{of}$. In this case, the forest and agricultural area can be treated independently from each other and we have two separate income optimization problems and corresponding land-use choices (the total optimal income, X^*, is equal to $X_f + X_a$):

Optimization of income from forest area, X_f:

$$\text{Maximize } X_f = p_p A_p + MIA_f A_f \tag{10}$$

Subject to: $A_\mathrm{p} + A_\mathrm{f} = A_\mathrm{of}$ Land constraint

This simple optimization problem has a corner solution where $A_\mathrm{p} = 0$ and $A_\mathrm{f} = A_\mathrm{of}$ if $p_\mathrm{p}/MIA_\mathrm{f} \in (0,1)$ and $A_\mathrm{p} = A_\mathrm{of}$ and $A_\mathrm{f} = 0$ otherwise (Figure 2, left panel).

Optimization of income from agriculture production, X_a:

$$\text{Maximize } X_\mathrm{a} = MIA_\mathrm{c}A_\mathrm{c} + MIA_\mathrm{l}A_\mathrm{l} \tag{11}$$

Subject to: 1. $A_\mathrm{c} + A_\mathrm{l} \leq A_\mathrm{tot}$ Land constraint allowing for use of forest

2. $L_\mathrm{c} + L_\mathrm{l} \leq L_\mathrm{a} + L_\mathrm{h} = L_\mathrm{f} - L_\mathrm{o} + L_\mathrm{h}$ Labour constraint

3. $(A_\mathrm{c} - A_\mathrm{c}^0)i_\mathrm{c} + (A_\mathrm{l} - A_\mathrm{l}^0)i_\mathrm{l} + wL_\mathrm{h} \leq C$ Capital constraint

The solution to this optimization problem is found where the income function, X_a, when pushed in the direction perpendicular to its slope, meets the first point where the constraints intersect (Figure 2, right panel).

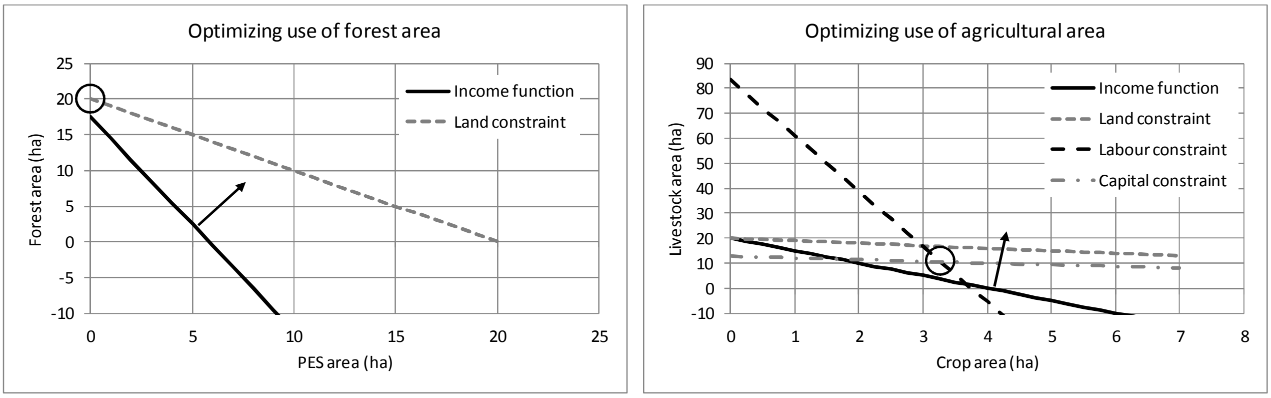

Figure 2: Illustration of the two separate optimization problems (example data used are: $A_{of} = 20$ ha, $A_a = A_{tot} - A_{of} = 20$ ha, C=400 US\$/year, L_a=2.5 cap, L_h=0.1 cap). The optimal solutions are indicated by circles.

Generally, HHs in the present study are constrained by either labour or capital, because of large average farm sizes. It can be shown that if either the labour or the capital constraints are relaxed, we get the trivial solution that the optimal/maximum agricultural area is equal to the total farm area in which case only the opportunity cost ratio between agriculture and forest or PES, OC(*a*,*f*/*p*), determines how land is used. Therefore, the optimal solution in terms of HH net income maximization is found where constraints 11.2 and 11.3 intersect. Solving constraint 11.2 for A_l and inserting the solution in constraint 11.3 gives the optimal/maximum crop area A_c^*:

$$\frac{A_c}{e_c} + D_l \frac{A_l}{e_l} = L_a + L_h \Rightarrow$$

$$A_l = \frac{e_l}{D_l}\left(L_a + L_h - \frac{A_c}{e_c}\right) \text{ and } A_c^* = \frac{\frac{e_l}{D_l}(L_a + L_h) - \left[A_l^0 + \frac{1}{i_l}\left(C - wL_h + i_c A_c^0\right)\right]}{\frac{e_l}{D_l e_c} - \frac{i_c}{i_l}} \tag{12}$$

Inserting A_c^* back into eq. 11 (constraint 11.3) gives A_l^* and the sum of the two gives the maximum agricultural area that a HH can be expected to cultivate/manage in order to maximize income:

$$A_a^{\max} = (1-k)\frac{e_l}{D_l}(L_a + L_h) + k\left[A_l^0 + \frac{1}{i_l}\left(C - wL_h + i_c A_c^0\right)\right] \; where \; k = \frac{\frac{e_l}{D_l e_c} - 1}{\frac{e_l}{D_l e_c} - \frac{i_c}{i_l}} \; for \; D_l e_c \neq 0 \tag{13}$$

Inserting eq. 13 back into eq. 9, we obtain an estimate of the possible overlap between forest area and agricultural area based on the HH's farming efficiency (e_c, e_l, D_l) and labour (L_a + L_h) and capital (C) endowment (e.g. cash input from the PES-payment):

$$A_d = A_{tot} - A_{of} - \phi\left[(1-k)\frac{e_l}{D_l}(L_a + L_h) + k\left(A_l^0 + \frac{1}{i_l}\left(C - wL_h + i_c A_c^0\right)\right)\right] \quad |A_d| \leq A_{tot} \tag{14}$$

The capital constraint in eq. 11.3 expresses that any expansion of the present agricultural area (A_c^0 → A_c, A_l^0 → A_l) has a per-hectare conversion cost (i_c, i_l). In reverse, present crop and particularly livestock area represent a certain value, which can be untied if e.g. the livestock area is reduced. Therefore, even without access to cash capital, livestock can be sold to finance an expansion of the crop area, given that MIA_c is greater than MIA_l. For simplicity's sake the sale/reduction of e.g. livestock area is set at the value of initial conversion/establishment.

3.3 Modelling the expected participation based on HH opportunity costs - Model part 3

The measure A_d is a key PES participation decision variable that determines whether there is a risk of a HH's agricultural activity encroaching on the available forest area. If it is highly probable that $A_d > 0$, a simple situation exists, where the forest area that can be expected enrolled in a PES-programme (up to PES programme maximum = $A_p^{\max}$) depends only on the opportunity cost ratio between PES-payment, p_p, and forest derived income ($MIA_f = y_f p_f$):

$$\begin{aligned} &if\ A_d > 0\ then\ if\ p_p > MIA_f\ then\ A_p = \min(A_{of}, A_p^{\max})\ and\ A_f = 0 \\ &\qquad else\ A_p = 0\ and\ A_f = \min(A_{of}, A_p^{\max}) \end{aligned} \tag{15}$$

This can be reformulated using again the rectangular function, *H*(*x*):

$$A_p = H(OC(p,f))\min(A_{of}, A_p^{\max})\quad and\quad A_f = A_{of} - A_p \tag{16}$$

where $OC(p,f) = p_p/MIA_f$ is the opportunity cost ratio between PES-payment and the marginal income from forest production. If, on the other hand $A_d < 0$, we cannot expect that all eligible forest area will be enrolled in a PES-programme if either the marginal income from agricultural production or the marginal income from forest production exceeds the PES-payment. Combined with eq. 16, this condition gives the following model for how much eligible forest one HH is expected to allocate under the PES-programme:

$$A_p = H\left(\frac{p_p}{MIA_f}\right)\left(\min(A_{of}, A_p^{\max}) - \left(1 - H\left(\frac{p_p}{MIA_a}\right)\right)\left(P\left(A_d \geq 0\right) - 1\right)A_d\right) \tag{17}$$

The final opportunity cost participation model (OC-participation model) in eq. 17 has four key variables (three of which summarizes a number of HH and contextual variables): i) opportunity cost ratio between PES-payment and forest income, ii) the maximum eligible forest area – a PES-programme specific criteria, iii) the per-hectare opportunity cost ratio between PES-payment and income from own-farm production, and (iv) the expected degree of overlap between forested area and agricultural area. The term $P(A_d > 0)$, i.e. the probability that A_d is positive, has two roles: i) to change the sign of A_d if negative so that A_d is correctly subtracted from A_p, and ii) to allow for uncertainties in actually defining/measuring $A_{\max}$ and hence A_d. It is seen from eq. 17 that the OC-participation model is not a 0/1 participation decision model, but rather gives an actual value of the eligible forest area that can be expected to be enrolled in a PES-programme.

4 RESULTS

The results of the model application are presented in two successive steps:

1. Test of whether the proposed labour allocation, additionality and participation models can mimic the data that was collected in El Castillo and Maquenque reasonably well;
2. Application of the OC-participation model to a selection of typical agricultural HHs to investigate how and to which degree key contextual factors affect participation and additionality

The HH-specific parameters in the model have been estimated based on case study questions and answers, and two constants in the labour sub-model (ratio between available labour and total HH size and the relationship between HH education level and time allocated for skilled non-farm work) have been estimated using data across HHs.

4.1 Test of sub-models

4.1.1 The labour allocation model (estimation of L_a)

Family size and labour time data from the PES and control groups in El Castillo and Costa Rica have provided the estimates of the ratio between HH size, N_h, and available labour time, L_t, presented in Table 1.

Group	N_h **(persons)**	L_t **(persons)**	α_f (%)	**Comment**
NICA-PES	6.5	3.7	56%	12 households (all PES-participants)
NICA-CON	5.1	2.7	53%	20 households (all participants)
CR-PES	3.3	2.7	81%	12 households (agricultural HHs out of 54)
CR-CON	3.7	3.1	85%	9 households (agricultural HHs out of 21)

Table 1: Study data of household size, maximum labour time and calculation of α_f (parameter in eq. 1).

It is seen that HHs in El Castillo are generally larger and have more children, which explains why the available labour time ratio is lower here (average 55%) than in Costa Rica (average 83%) even though the families are smaller. An average of the above group values has been used for α_f in all subsequent model applications. The second unknown parameter in the labour sub-model is f_n, which relates average HH education level (*edu*) to the expected amount of time that can be allocated for skilled non-farm work, L_e (eq. 3). Although there is a non-linear variation when looking at the individual HHs and their aptitude to acquire income from non-farm work, there appears to be an approximately linear relationship when using group averages. Figure 3 illustrates the group-average HH education level and degree of non-farm labour (and income) relative to the total labour time available.

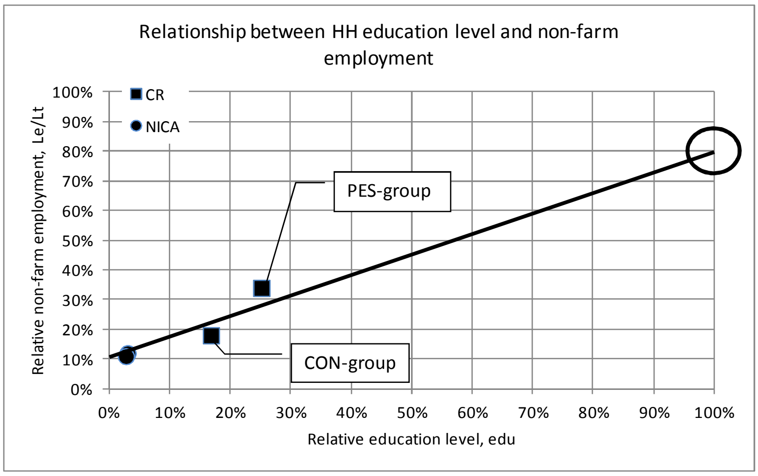

Figure 3: Education level (eq. 2) and degree of reported non-farm work (eq. 3). Markers show group-average data. The circle indicates the estimated maximum employment ratio = the labour model parameter f_n. The constant a_0 = 10% (intercept).

Figure 4 presents the average results of the labour allocation model applied to data from the individual HHs in the PES and CON groups in Nicaragua and Costa Rica, respectively.

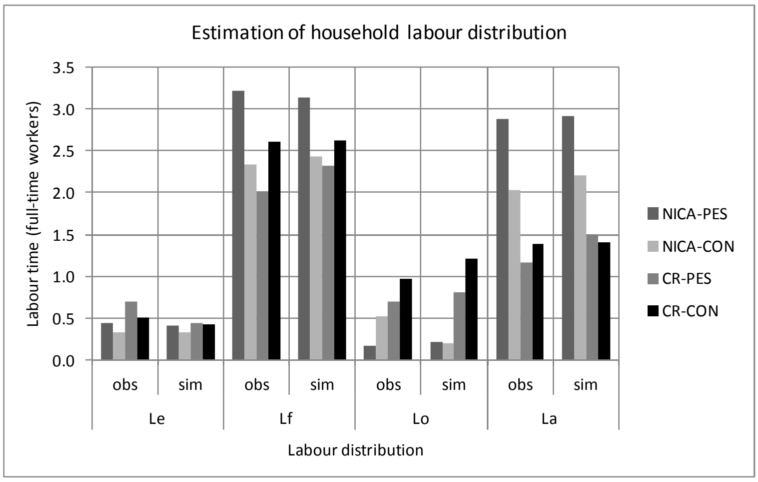

Figure 4: Estimated and observed farm labour (L_a) distribution for the four survey groups. In the L_a-model, a value of f_0 = 50% has been assigned to those households who have not explicitly reported on this parameter.

Although the labour allocation sub-model may not capture the exact distribution of labour in individual HHs, the model gives good estimates of how HHs allocate time for various potential income sources when looking at the averages of simulated compared to actual individual HH's labour distribution.

4.1.2 Additionality: Land allocation models (estimation of A_a^{max} and A_d)

With the sub-model for estimation of HH labour distribution validated, we continue with estimating the maximum agricultural area a HH is able to cultivate given the available resources (labour input, production effectiveness and potential cash capital from PES-payment). Based on case study interview data, we have estimated the maximum agricultural area each HH can manage, A_a^{max}, and subsequently the relative potentially overlapping area between agricultural area and forest cover, $a_d = A_d/A_{tot}$, for the four case study groups, see Figure 5.

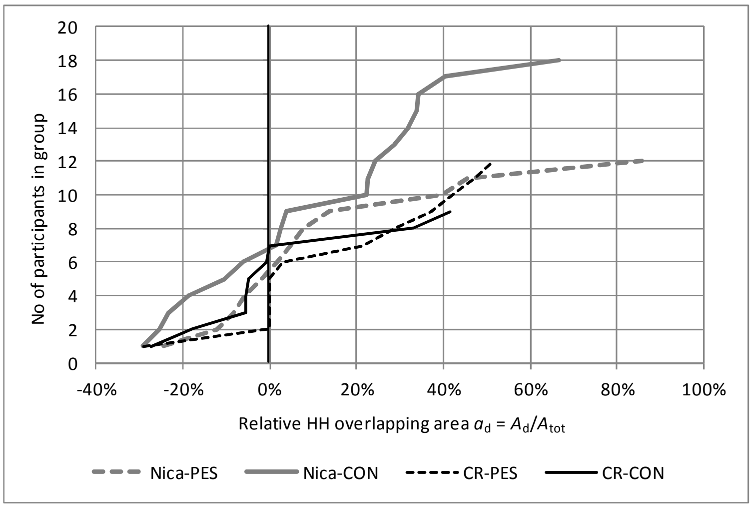

Figure 5: Distribution of the relative overlapping area, a_d, for the four surveyed groups. The four curves show the accumulated a_d illustrating the number of HHs in each group that has negative overlapping areas.

In all four groups, some HHs are likely to encroach on forest area to expand agriculture (5 in Nica-PES, 6 in Nica-CON, 1 in CR-PES and 6 in CR-CON). Most of the HHs, however, have more land available for agriculture than they can realistically utilize. In the two Costa Rica groups, only those HHs that use their farms for agricultural purposes have been included in the above estimates. As all other HHs per definition have $A_d > 0$, it appears that additionality of the PES-programme in Maquenque is minimal, unless a real risk of sale or land renting exists for agricultural purposes. In Nicaragua only five HHs in the PES-group had $A_d < 0$ and represented a real risk of deforestation. Thus, the first condition of additionality is that $A_d < 0$; otherwise the PES-programme pays for protecting forest that is not likely threatened by clearing for agriculture purposes.

As a second condition of additionality PES-payment must at least compensate the marginal income from forest use for $A_d > 0$, and the marginal income from agriculture (or forest if $MIA_f > MIA_a$) for $A_d > 0$ to induce participation.

PES-programme additionality (realized for the two PES-groups, and simulated for the two CON-groups) is illustrated by plotting max(MIA_f, MIA_a) against A_d and for a given PES payment = 30 US$/ha in El Castillo and 64 US$/ha in Maquenque (Figure 6). It shows that additionality is limited in both PES-programmes.

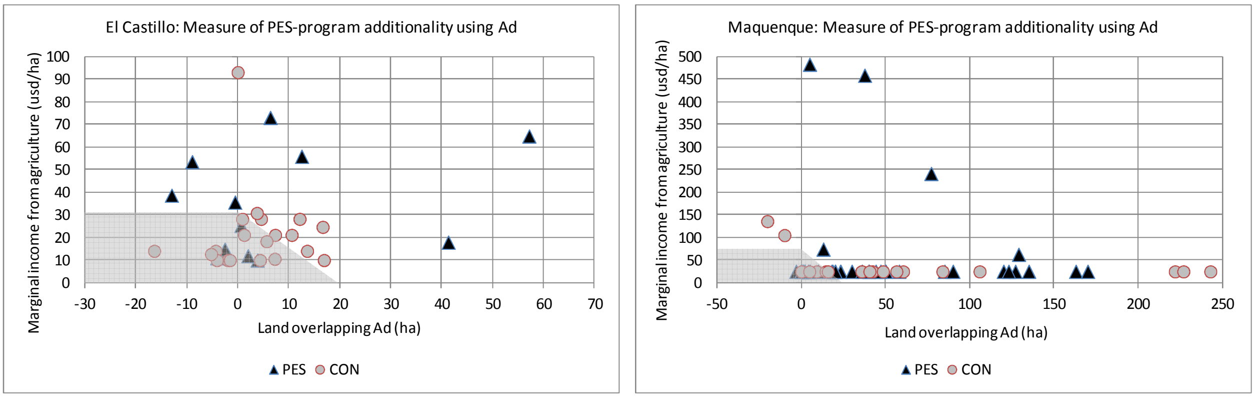

Figure 6: Estimation of PES-programme additionality in the two case study areas: Nicaragua/El Castillo (left panel) and Costa Rica/Maquenque (right panel). The shaded areas show the respective* Additionality Regions*, the triangle spanning 0 <* A_d *< 20 ha is to allow for the uncertainty in the estimation of* A_d*. Actual PES rates applied.

The HHs that fall within the *Additionality Region* contribute to the additionality of the PES-programme, those outside do not.

4.1.3 Explanatory model for predicting participation (A_p model)

Using the reported HH information and the derived HH economic data, the expected participation can be estimated using eq. 17. Figure 7 show the results of the estimated participation for the two PES-groups compared to observed.

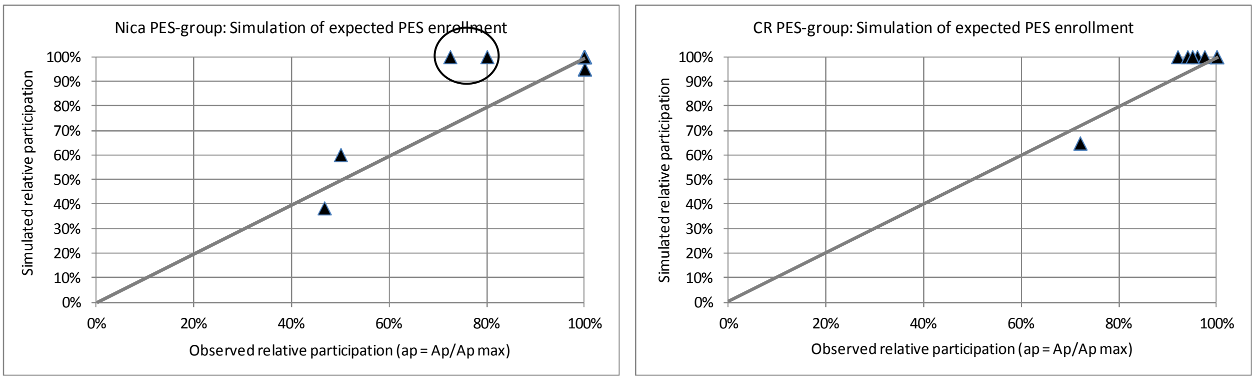

Figure 7: Estimation of the PES-participation for the two surveyed PES-groups (Nicaragua left and CR right).

Most participants have enrolled the maximum eligible forest area, which is also predicted by the model. Only 4 of 12 participants in El Castillo and 1 of 54 participants in Costa Rica have enrolled less. These participants are the agriculturally most productive, and have relatively smaller farms and larger HHs. For 2 of the 4 HHs in the NICA PES-group, which have enrolled less than the eligible forest (circled in Figure 7), the OC-participation model suggests that participation should have been 100%. This could be explained by non-pecuniary factors explicitly not included in the model, e.g. lack of trust in the PES programme and/or private transaction costs, which tends to *de facto* reduce the perceived opportunity cost ratio between PES and income from forest (Vinqvist unpublished). Overall, though, the OC-participation model appears to give results consistent with the observed degree of participation.

The nature and size of the PES cases investigated gives us modest empirical data against which to check model predicted participation. However, during the case study interviews with the control group in Maquenque, Costa Rica, a number of randomly selected participants were asked to state how large a portion of their farm forest area they would be willing to enrol in a PES-programme at which price. The enrolled forest area as a function of offered price for i) the stated preferences (black line) and ii) simulated enrolment (dotted line) is shown in Figure 8.

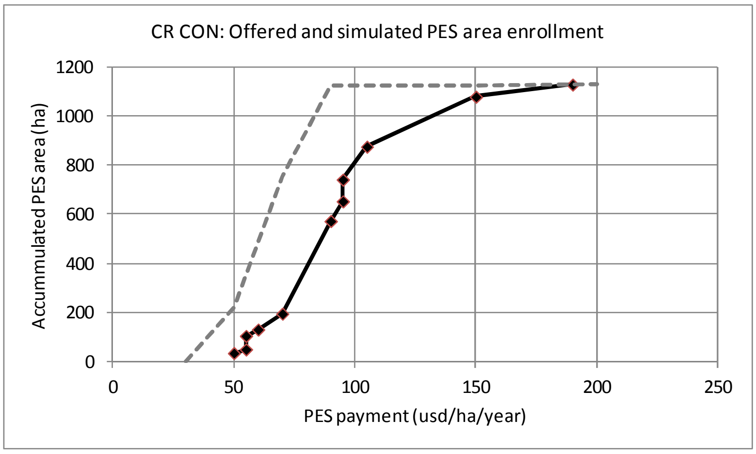

Figure 8: Accumulated forest area as a function of price offered. The black curve shows the result of the "auction" proposed to a sub-set of the Maquenque CON-group. The dotted curve shows the result of the OC-participation models prediction of forest area enrolment.

Based on the stated preferences given by the selected participants, the derived farm productivity data and opportunity costs ratios $OC(p,f)$ and $OC(p,a)$, the participation model estimates a PES-area sum-curve, which is shifted by 25-50 US$/ha to the left compared to the stated preferences. This shift implies that either the perceived value of land is 1.5-2 times the estimated marginal incomes or opportunism inflated bids, providing an indication of the private information rents sought by potential participants.

4.2 Model applications

4.2.1 Sensitivity analysis

The purpose of sensitivity analysis is to identify those variables/parameters that are most influential for the outcome of a given model. If we return to the final OC-participation model in eq. 17, we see, if we regard A_{of} as an independent forcing variable, that the model contains four key variables: A_{d}, MIA_{f}, MIA_{a} and p_{p} and we can calculate the relative sensitivity coefficients:

$$\beta_i = \frac{\partial A_p}{\partial x_i}\frac{\overline{x_i}}{\overline{A_p}} \tag{18}$$

The result of the primary sensitivity analysis is presented in Figure 9.

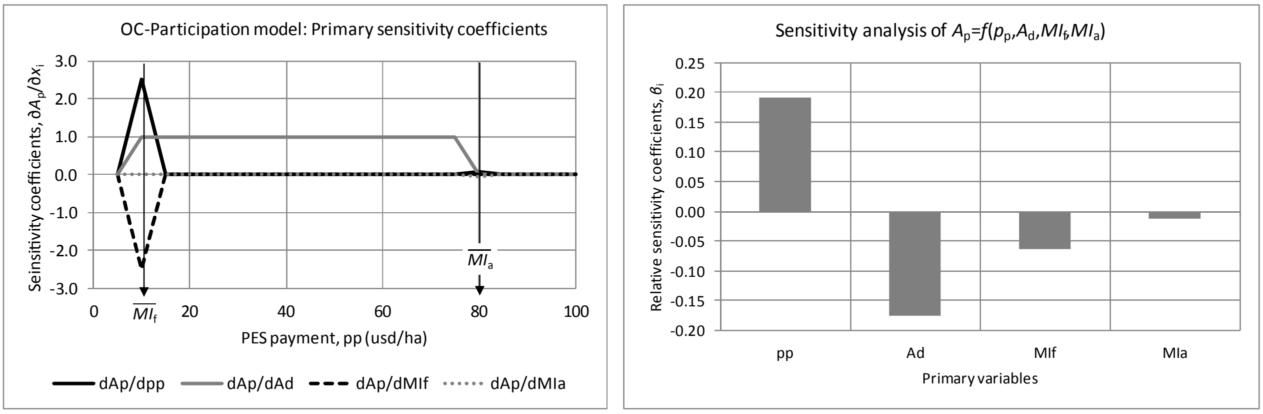

Figure 9: Sensitivity analysis of the OC-Participation model. Primary sensitivity coefficients as function of the PES-payment (left panel) and primary relative sensitivity coefficients, β_i (right panel).

Clearly, the PES-payment has a direct, significant and positive effect on the expected degree of relative participation ($a_{\mathrm{p}} = A_{\mathrm{p}}/A_{\mathrm{of}}$). The other three variables, which are functions of the basic HH and contextual conditions, all have a negative effect on the expected participation. Recalling that A_{d} measures the potential overlap between use of land for agriculture or forest, we see that participation decreases, when overlap increases. Likewise, an increase in the marginal income from forest and/or agriculture will, given a fixed value of p_{p}, result in a decrease in the expected PES-participation. Second to the PES-payment, A_{d} is throughout the realistic range of PES-payments (0-80 US$/ha) the most influential primary variable. Therefore, using the A_{d}-model in eq. 14 we subsequently calculate the relative sensitivity coefficients for the variables/parameters that determine A_d (Table 2).

Variable/Parameter	**Unit**	**Average value**	**Relative sensitivity**
$\boldsymbol{C}$	US$	400	-0.1045
$\boldsymbol{N}_\mathrm{h}$	persons	6.5	-0.0751
$\boldsymbol{e}_\mathrm{c}$	ha/person	1.5	-0.0656
$\boldsymbol{y}_\mathrm{c}$	kg/ha	800	-0.0479
$\boldsymbol{p}_\mathrm{c}$	US$/kg	0.66	-0.0328
$\boldsymbol{r}_\mathrm{s}$	%	0.5	-0.0327
$\boldsymbol{e}_\mathrm{l}$	heads/person	40	-0.0088
$\boldsymbol{f}_\mathrm{n}$	%	0.8	0.0064
$\boldsymbol{edu}$	%	10	0.0065
$\boldsymbol{D}_\mathrm{l}$	heads/ha	1.2	0.0087
$\boldsymbol{i}_\mathrm{c}$	US$/ha	130	0.0120
$\boldsymbol{f}_\mathrm{o}$	%	0.5	0.0327
$\boldsymbol{W}$	US$/year	700	0.0328
$\boldsymbol{i}_\mathrm{l}$	US$/ha	185	0.0907

Table 2: Result of the sensitivity analysis for a set of average parameter values. Relative sensitivity coefficients are first calculated based on eq. 14 ($\partial A_d/\partial x_i$) and then multiplied by $\partial A_p/\partial A_d = -0.18$ obtained from the primary sensitivity analysis of eq. 17. Variables are sorted according to relative sensitivity in ascending order.

Results show 7 of 14 variables as having a negative effect on participation. Moreover, 4 of the 5 numerically most significant variables (C, N_h, e_c and y_c) have negative relative sensitivity coefficients demonstrating that when they increase, A_p decreases. The livestock area unit conversion cost, i_l, is the variable having the most positive influence on participation. It should be noted that according to eq. 14 the sensitivity coefficients of the two binding input variables A_tot and A_of per definition are equal to 1 and -1, respectively. Hence, participation is proportional to A_tot and inversely proportional to the pre-PES forest area: the bigger the forest area is relative to the total farm area, the higher is the risk of land-use competition and therefore, *ceteris paribus*, also the probability that not all forest area is converted to PES.

4.2.2 Model scenarios illustrating how key contextual factors affect participation and additionality

To illustrate the influence of key external factors on participation and land use change, i.e. implicitly additionality, three different scenarios have been selected with varying values of f_o (off-farm market access), C (capital) and $y_c e_c$ (crop productivity).

Since the OC-participation model structure is highly non-linear, using the model directly on group averages, alternative to taking group averages *after* simulations at individual HH level, can be misleading. Therefore, analyzing effects of changes in contextual factors requires the definition and selection of a group of representative HHs in terms of important key variables identified in the sensitivity analysis. The OC-participation model is then applied to each of the typical HHs and the average effects then calculated. We have defined 16 typical HHs by assigning each one a combination of four key HH characteristics (*Household size*, *Farm size*, *Education level* and *Farm productivity*) varied in two ways: high and low values. Two of the four variables are composite variables that are made up of a set of sub-variables. The four key variables and their values (or value sets) for the two extremes are shown in Table 3.

Variable	**High**	**Low**
1. Household size		
N_h (cap)	10	4
2. Farm size	Value set	Value set
A_{tot} (ha)	80	20
A_{of} (ha)	40	10
A_c^0 (ha)	6	2
A_l^0 (ha)	20	5
3. Education level		
edu	10%	1%
4. Farming productivity	Value set	Value set
y_c (kg/ha)	900	300
e_c (ha/cap)	3	1

y_l (calfs/heads)	0.25	0.1
e_l (heads/cap)	80	20
D_l (heads/ha)	2	1

Table 3: Test data for generation of 16 typical agricultural household combinations. The high and low values correspond approximately to the extremes of the observed range in the two groups in El Castillo, see Annex B.

The 16 typical (Nicaraguan) HHs represent all 16 combinations of the four characteristics each with two values (high, low). With these combinations as input, the OC-participation model is used to estimate family labour distribution, land-use distribution and the share of existing forest (A_{of}) likely to be enrolled in a PES-programme, assuming that all existing forest is eligible. For the remaining HH and contextual variables, we have in the following examples used average values obtained for the Nicaragua PES-group (insignificantly different from the CON-group), see Annex B. The *Average context* scenario is thus defined by $f_o = 50\%$, $C = 200$ US$, plus e_c and y_c from Table 3)

4.2.2.1 Change in off-farm labour market

Realised off-farm labour market wages, measured by the parameter $f_o w$, has a direct effect on the marginal income from agriculture and therefore on the opportunity cost ratio between PES and per-hectare income from agriculture, $OC(p,a)$. A_d is likewise dependent on $f_o w$ since increased access to paid off-farm work reduces time allocated for farm labour on own farm. Average results from the typical HHs are shown in Figure 10.

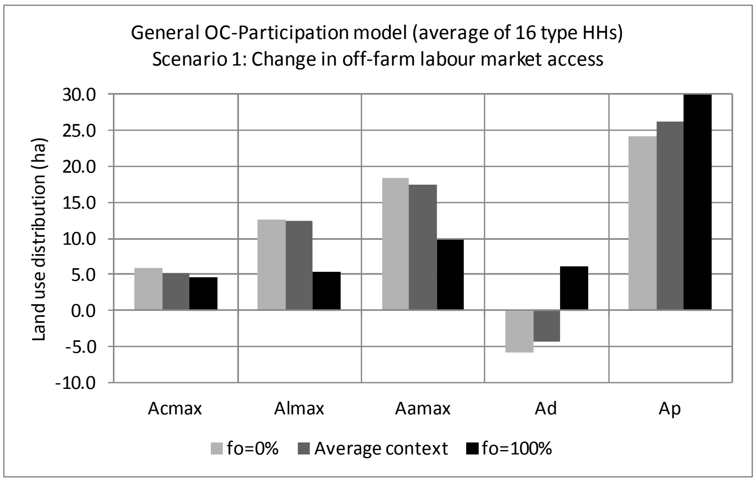

Figure 10: Simulation of the change in land-use as a result of change in f_o with C and $e_c y_c$ kept constant.

A change in f_o affects the size of the agricultural area, which decreases in response to increasing off-farm labour market access. This is the effect of farmers with low productivity preferring to take paid off-farm work and reduce own-farm work to meet subsistence consumption. Consequently, the land competition (A_d) that exists for $f_o = 0$ (- 6 ha) changes to land surplus for $f_o = 1$ (6 ha). The average PES-area increases by the same amount.

4.2.2.2 Capital increase due to cash income from PES

With PES enrolment HHs receive cash income corresponding to p_pA_p, which can be invested in expanding the agricultural production. Thus, there is a trade-off between the area enrolled under PES providing cash income, which is then lost for agricultural production, and an increased production effectiveness that could mean increased agricultural area, with the net difference corresponding to the risk of on-farm slippage.

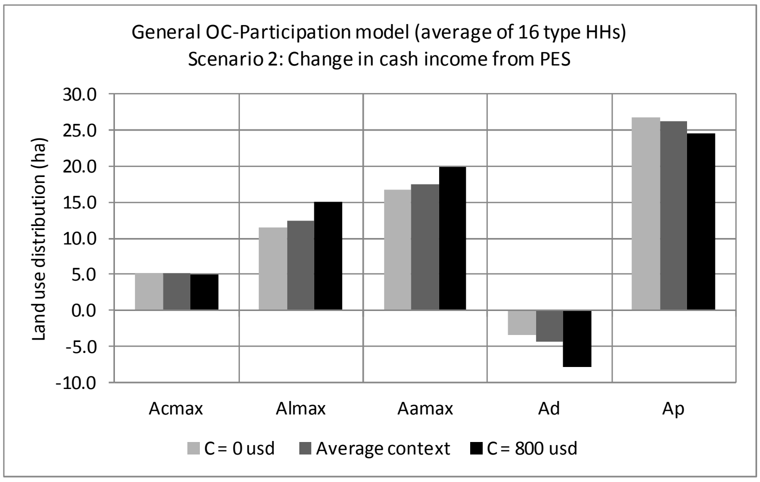

Figure 11: Simulation of the change in land-use as a result of change in cash income, C, received from PES.

The effect of increasing the amount of cash available for investment in agricultural production (investing 100% PES) is an increase in A_d and consequently a decrease in A_p, see Figure 11. The crop area is expected to decrease slightly and the livestock area to increase.

4.2.2.3 Green revolution

A realistic scenario over time is an improvement in per-hectare crop productivity (effectiveness multiplied by yield = e_cy_c). According to the OC-participation model, this would decrease the overall risk of competition between farming and forest.

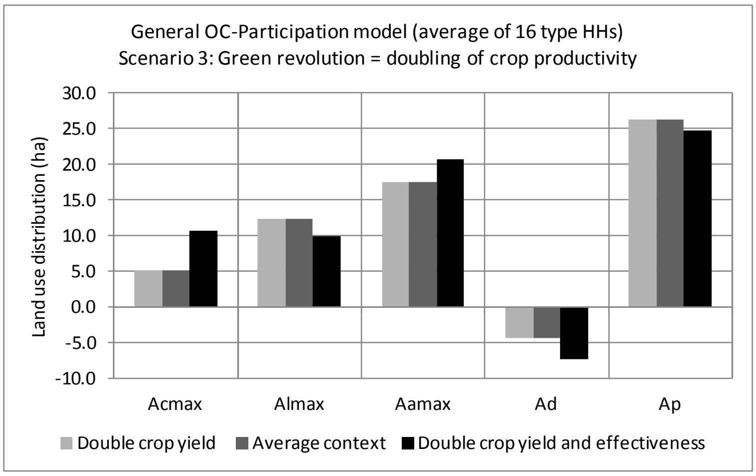

Figure 12: Simulation of the change in land-use as a result of an increase in crop productivity ($y_c e_c$) with constant f_o = 50% and* C *= 200 US$.

Doubling of the crop yield (kg/ha) alone does not influence the land-use distribution choice, but will clearly increase the income from cropping. However, if the crop farming effectiveness is increased the effect is a shift from livestock production to crop production. In this case, the total agricultural area will increase, resulting in a minor reduction of the expected PES-area.

5 DISCUSSION

5.1 The OC-participation model

The structure of the OC-participation model is based on non-controversial classical farm household models. As such, it constitutes a strictly economic skeleton of decision making in households, ignoring other aspects of decision making such as risk (e.g. related to trust and external chocks) and time preferences. While not impossible to incorporate in such a model, we have chosen not to in this initial step. This means the model operates on an assumption of economically rational behaviour. The specific choice of land uses and parameters included (and omitted) in the model reflects the site specific priorities and practices, leading us to ignore land renting and purchase of additional land, migration/remittances, ignore production costs other than labour input and consider PES the only source of capital.

Also, although comparatively more detailed than original farm HH models (land use categories, labour opportunity preferences and capital constraints), we have however naturally made a number of simplifications such as use of income maximisation as an approximation for utility, as well as linear formulations of production functions. The upside of this, however, is that the model allows for a limited set of quantifiable and unit-true key variables/parameters to be estimated directly from HH interviews, prices of key crops and livestock, labour wages and market opportunities, while still retaining a reasonably robust predictive power. This enables direct and reversible translation of model and model input and output with measurable empirical observations, which a strictly theoretical formulation using e.g. Cobb-Douglas function(s) would not.

Likewise, various simplifications have been made in order to enable an analytical solution to the HH income optimization model. It is assumed that production is riskless and that prices, off-farm work preference/availability and wages are not affected by HH decisions, i.e. the HH is assumed to be a price-taker in the primary markets. Since we are looking at HH-related characteristics in a static environment, the participation model does not include income from renting out land or from exogenous factors such as selling land to e.g. large oil palm or pineapple plantations (also sources of off-farm labour). The static nature of the model also ignores land use dynamics beyond one-cycle-at-a-time, such as the possible need for continued deforestation for reasons of dropping soil fertility. This, however, is to some degree countered by the inclusion of fallow land (up to 40% of total agricultural area) among land uses, which at least for some farmers appear adequate (by e.g. inclusion of green cropping between other crops).

It should also be emphasized, that predictions at individual HH level must be interpreted with caution because of the non-linearity of the labour sub-model. Group level averages of model predictions are preferred for this reason.

However, using collected empirical information, it is shown how the OC-participation model can be used to quantity the relationships between HH livelihood strategies and marginal income from various activities and expected PES programme impact, respectively. Applying the model to predict participation and additionality at HH level and contrasting this with observed HH decisions of the four participant groups generally confirmed robustness of the model, where direct data were available for comparison. Data to evaluate the model’s ability to predict participation were less useful, *ceteris paribus*, than they could have been due to the widespread non-existing opportunity costs. Still, stated preferences available from field work in the Costa Rica case corroborated the pattern of participation, with a difference in absolute values possibly due to opportunism or difference in perceived and calculated opportunity costs.

5.2 Model applications

While by no means exhaustive, the three model simulations included here illustrate the use of the model for policy planning purposes, and demonstrate the importance of acquainting oneself with exogenous key factors such a availability of non- and off-farm work, as well as possible capital constraints. In describing income maximization as a driver of land and labour allocation, the model draws attention to several interesting aspects not commonly addressed in PES literature and PES policy planning. For one, the simulation of PES as easing a capital constraint illustrates a possible dilemma in PES between conservation and welfare increases, as payments may be invested in increasing agricultural production to the benefit of HH welfare and detriment of ES provision. Likewise, an interesting intermediary result of estimating additionality is the illustration of shifting prioritisation of area dedicated to livestock versus cropping. If other policies are simultaneously trying to stimulate e.g. intensification of agriculture, these should be informed by the potential effects of parallel introduction of PES. In the best case scenario, synergies would be possible. In the worst case some impacts may cancel each other out.

The simulations also illustrate the workings of intra-household trade-offs, which may potentially result in on-farm slippage undermining overall PES additionality and changes between prioritized land uses on existing agricultural land and in livelihood strategies (farm or non-/off farm income). In doing so, the model may be used to investigate the essential economic skeleton behind policy impacts *a priori* and thus inform policy design. The local issue of trust described by Vinqvist (unpublished) illustrates that the model should not be the only tool employed in planning a PES intervention. However, insofar as addressing the cost-effectiveness loss from information rents commonly paid out by PES programmes, mapping additionality and the potential participation, if no substantial social norms influence this, the model serves its purpose. By giving a differentiated estimate of opportunity costs across a potential policy target group, the model can assist in assessing the appropriate level of payment given a desired area-based coverage or a limited budget. More specifically a sum curve can be drawn describing how many hectares are likely to be enrolled in a PES programme given a certain price. Using a flat price, it may simultaneously provide an estimate of the private information rents paid out by the programme or put differently the loss in cost-effectiveness accrued by employing uniform payments.

The many different outcomes of model simulations depending on the composition of a number of target group characteristics stress the need for adaptation to local conditions. Indeed, rather than poverty status pre-PES it seems the original asset bundle combination, which guides PES impact. In our simulations 16 constructed HHs (but based on empirically observed variations) serve to capture the potentially indefinite variations of HH characteristics, i.e. ensure a certain degree of representativeness of the 'input' HHs relative to the actual target group. The number 16 is somewhat arbitrary, and should be modified to reflect the diversity of the target population, guided by the sensitivity analysis, which suggests that pre-PES data collection can advantageously be concentrated on the quantification of (i) present land-use and HH labour distribution (A_{tot}, A_{of}, A_c, A_l, A_f, N_f, edu); (ii) cash endowment (C) and unit land conversion costs (i_c, i_l); (iii) crop and livestock farming productivity and prices (e_c, y_c, e_l, D_l, y_l, r_s, p_c, p_l); and (iv) off-farm market environment (f_o, w).

6 CONCLUSIONS

The study has produced what looks like a promising start to a theoretically founded, but empirically useful tool for policy analysis, the OC-participation model. Testing the model on empirical case study data indicates robustness of the model within a scope of marginal, rural areas in developing countries.

Supported by empirical data, the model in turn has helped answer the two central research questions posed in section 1.3: i) how does PES impact land and labour allocation; and ii) which up-front HH and contextual characteristics are decisive for participation and additionality of PES?

Addressing the first question, both empirical data and model simulations support the importance of both household and external factors as conditioning for the effect of PES on land and labour allocation. This stresses the importance of local settings for PES impact and of looking beyond one uniform private OC across a PES target group as the single economic factor deciding participation. As a side benefit of the model calculating more differentiated and detailed OC, it provides a simultaneous indication of environmental impact, i.e. additionality, through resulting land allocation. The latter may have a value as circumstantial evidence in lieu of the elusive counterfactual scenarios necessary to document PES additionality.

In answer to the second question, the model indirectly explains why initial poverty status (e.g. cash income per day per capita) as such is a poor indicator of participation, and points to the collective initial asset bundle as realised by asset holders (farmers) as the relevant point of departure. In doing so, it guides information gathering before policy design is undertaken, pointing to the pertinent and practically feasible data collection needed for a relatively robust prediction of economic motivations for participation and additionality.

Using the OC-participation model to mimic possible realistic scenarios allows the identification of crucial external factors in a PES setting as access to capital and the off- and non-farm labour market.

Overall, the OC-participation model contributes to narrowing the gap between practical and theoretical PES related research, providing directly measurable and logical links between target group characteristics and policy outcome, useful to practitioners and testable by academics. Any feedback on both the former and the latter is welcomed.

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ANNEX A: Variable/Parameter list

Variable/parameter	Unit	Description
A_{tot}	ha	Total farm area
A_{p}	ha	PES area
A_{f}	ha	Forest area
A_{c}	ha	Crop area
A_{l}	ha	Livestock area
A_{r}	ha	Fallow/rotation area
A_{of}	ha	Original forest area
A_{s}	ha	Subsistence area = minimum required to sustain the family
A_{c}^{0}	ha	Present crop area (before PES intervention)
A_{l}^{0}	ha	Present livestock area (before PES intervention)
L_{c}	persons	Labour required to manage crop farming
L_{l}	persons	Labour required to manage livestock farming
L_{o}	persons	Off-farm labour
L_{h}	persons	Hired labour
L_{t}	persons	Total HH labour
L_{e}	persons	Non-farm labour
r_{s}	%	Share of farm production that is sold
p_{p}	US$/ha	PES payment
P_{f}	US$/tree	Selling price of wood
p_{c}	US$/kg	Selling price of crops (average of 5 key crops)
p_{l}	US$/head	Selling price of cattle
y_{f}	trees/ha/year	Forest production
y_{c}	kg/ha/year	Crop production (average of 5 key crops)
y_{l}	%/year	Livestock production (proportion of the stock that is sold)
e_{c}	ha/cap	Crop farming effectiveness
e_{l}	heads/cap	Livestock farming effectiveness

D_l	heads/ha	Average livestock density
i_c	US$/ha	Unit cost of converting forest/fallow into crop land
i_l	US$/ha	Unit cost of converting forest/fallow into livestock land
f_o	%	Off-farm labour market access frequency
w	US$/year	Off-farm labour wage
f_n	%	Non-farm labour market access frequency
w_n	US$/year	Non-farm labour wage
C	US$/year	Cash capital
MIA_f	US$/ha	Area-specific marginal income from forest
MIA_c	US$/ha	Area-specific marginal income from crop production
MIA_l	US$/ha	Area-specific marginal income from livestock production
MIC_c	US$/cap	Person-specific marginal income from crop production
MIC_l	US$/cap	Person-specific marginal income from livestock production
X_t	US$/year	Total HH income
X_e	US$/year	HH income from non-farm work
X_o	US$/year	HH income from off-farm work
X_a	US$/year	HH net income from farm production
X_p	US$/year	HH net income from PES

ANNEX B: Average variable/parameter values in Nicaragua (El Castillo) and Costa Rica (Maquenque)

Variable/parameter	Unit	Nica PES	Nica CON	CR PES*	CR Con*
A_{tot}	ha	88	33	131	114
A_{p}	ha	21	0	93	0
A_{f}	ha	40	16	24	93
A_{c}	ha	4.0	2.6	1.9	0.4
A_{l}	ha	11	6.9	4.1	0.0
A_{r}	ha	11	7.2	7.1	8.2
A_{of}	ha	61	16	117	93
A_{s}	ha	4.7	2.8	0	0
N_{h}	persons	6.5	5.1	3.3	3.7
L_{t}	persons	3.7	2.7	2.7	3.2
L_{e}	persons	0.4	0.3	0.9	0.5
L_{f}	persons	3.2	2.4	1.8	2.7
L_{a}	persons	2.9	1.7	0.7	1.4
L_{h}	persons	0.1	0.05	0.2	0.4
L_{o}	persons	0.2	0.5	0.3	0.6
edu	%	3.0	2.8	25	17
r_{s}	%	30	34	62	18
p_{p}	US$/ha	30	0	64	0
P_{f}	US$/tree	50	50	180	180
p_{c}	US$/kg	0.66	0.66	0.75	0.75
p_{l}	US$/head	165	165	204	204
y_{f}	trees/ha/year	0.2	0.2	0.2	0.2
y_{c}	kg/ha/year	654	740	2545	964
y_{l}	%/year	0.19	0.25	0.30	0.30
e_{c}	ha/cap	1.5	1.7	2.8	2.0

e_l	heads/cap	40	45	27	49
D_l	heads/ha	1.2	1.2	2.3	2.7
i_c	US$/ha	130	130	250	250
i_l	US$/ha	185	185	400	400
f_o	%	0.6	0.7	0.6	0.6
w	US$/year	700	700	2,900	2,900
f_n	%	0.8	0.8	0.8	0.8
w_n	US$/year	2,150	2,150	7,530	7,530
X_t	US$/year	2,257	1,724	19,600	9,880
X_e	US$/year	956	703	5,218	3,794
X_o	US$/year	120	363	2,018	2,848
X_a	US$/year	447	625	8,330	3,238
X_p	US$/year	628	0	4,034	0

* Agricultural households only