A household livelihoods view: analyzing opportunity cost components to understand PES impact on households in El Castillo, Nicaragua

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Abstract: Understanding payments for environmental services' (PES) potential and constraints for particularly poorer farmers in the developing world has long been a focus of PES related research. There is, however, still a gap between theoretical and practical approaches, when trying to identify and quantify these opportunities and constraints. With a view to understanding livelihood strategy components' individual interaction with and influence on PES impact, the present paper sets forth to apply an empirically based household income model to bridge this divide. The model calculates household income based on initial natural, financial and labour asset combinations and can estimate income, land and labour use changes as a result of PES introduction under different conditions, assuming economic rationality. Employing the model to simulate introduction of PES to a control group in El Castillo, Nicaragua, under different capital and labour market conditions, reveals the particular importance of family farm labour, capital constraints and local labour market conditions in shaping the social and environmental impact of PES, and pointing to a possible risk of on-farm leakage as a secondary consequence of PES by easing a pre-PES capital constraint.

Key words: PES, forest protection, household model, private opportunity costs, participation, information rent.

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1 INTRODUCTION

1.1 Background

Programs providing payments for environmental services (PES) have been suggested as a policy tool in developing countries and under conditions of weak governance. Reinvented in the last 10-15 years to increase directness and efficiency in conservation interventions (Ferraro & Kiss 2002), they have since in practice and in a developing country context been expanded with a desire to use payments as a poverty alleviation measure as well (e.g. Pagiola et al. 2005; Landell-Mills & Porras 2002). This has naturally lead to a host of research into primarily participation constraints, i.e. if and under what conditions the poor might or might not be able, willing and eligible to participate in PES programmes (Pagiola et al. 2005). Part of this research, namely that into constraints to the willingness to participate, is relevant to understanding the variations in PES impact experienced by poorer households (HHs). Since participation is voluntary, willingness to participate hinges on the perception of PES fitting into existing livelihood strategies and a gained advantage, i.e. typically that payments match or supersede the foregone income from the best, realistic alternative land use, i.e. private opportunity costs (POC).

For primarily political reasons POCs are almost entirely designed as flat rate payments, i.e. offering the same payment to all participants regardless of the private cost of environmental service (ES) provision and the level and quality of ES. This to some extent negates the rationale behind introducing market-based mechanisms in environmental service provision: that markets are more efficient at allocating resources, i.e. in this case securing ES provision with suppliers where the cost of providing this service is lowest. Central to efficient provision of ES are hence the POCs of potential ES providers, since this is the principal discriminating factor when attempting to target lowest-cost supply. In the context of PES, POCs constitute a crucial instrument for appropriate policy design in at least three ways:

1. For cost-effectiveness: if POC are much lower than payments, private information rents to participants render PES environmentally inefficient, but poverty alleviation objectives are potentially achieved to a relatively higher degree;
2. For environmental additionality: if POC are non-existent, additionality of the proposed policy is low or non-existent (aggregate and/or on-farm);
3. For socio-economic (poverty alleviation) additionality: if POC are higher than payments participation will be zero or limited, or alternatively detrimental to any intent of achieving poverty alleviation objectives.

Nevertheless, opportunity costs have received modest in-depth attention from PES researchers and even less from PES practitioners, as indicated by Pattanayak et al. (2010) (Appendix Table 3, column 1, p. 271) and Wunder, Engel and Pagiola (2008). Rather, private opportunity costs are frequently reported – if at all – as one uniform, average figure across a diverse range of potential participants and land uses. This approach disregards a number of both general and individual factors significantly influencing private opportunity costs, such as markets for non- and off-farm employment, farm productivity, access to credit and agricultural markets, excess or deficit of sufficient family farm labour and on-farm optimisation of land use depending on returns to livestock, crops and forestry. Since investigations into actual variation in opportunity costs are infrequent, we do not know the magnitude of efficiency loss due to private information rents, nor do we have an estimate of additionality. We also remain less informed of the on-farm land use changes, which may occur as a consequence of PES introduction, as well as the role PES may come to play in HHs' livelihoods strategy. We suspect the above mentioned chosen ignorance of variations in POC holds the answer to many of the widespread environmental inefficiencies and lack of additionality experienced by PES initiatives.

1.2 Problem formulation

Few implemented PES schemes have been well targeted and well documented in terms of impact. Poor targeting means low efficiency, and few baselines and impact measurements mean little empirically founded input for policy improvement. A number of factors have been found correlated with participation, and some theoretical models exist proposing 'how' and 'why' linkages of participation and impact. So far the 'why' and 'how' have rarely been empirically grounded, and a closer understanding of the interactions between rural livelihoods and PES impact is still incipient. Advances have been made in the understanding of what influences participation and to some extent POC. Participation determinants have by and large been sought elucidated through statistical correlation studies as those of e.g. Zbinden & Lee (2005), whilst more complicated theoretical models, such as that of Alix-Garcia et al. (2010) to a larger extent seek to predict and explain participation and land use changes following PES introduction. Whilst correlation studies have the advantage of being 'grounded' empirically, they have a weakness in not necessarily offering cause and effect linkages making predictions based on correlated parameters more uncertain. On the other hand the theoretical models offer such causal explanations, instilling more confidence in their predictive power. They, however, are often not empirically founded and their required inputs may be many and difficult or uneconomical to measure. To improve policy planning it is desirable to:

1. Understand which key intra-household and contextual economic parameters/conditions parameters modify PES impact; two of these (credit access and labour market) have only been considered in complex theoretical models;

2. Enable estimation of expected impacts from a PES programme intervention i) socio-economically and ii) environmentally; this has so far only been retrospectively examined; and
3. Enable prediction of such impact reliably based on a minimum of necessary input parameters, i.e. limited/targeted up-front data collection

We therefore propose to investigate private opportunity costs in HHs by means of a PES-adapted, but otherwise generic agricultural household income optimization model. Using a concrete case study of a PES habitat protection scheme in El Castillo, Nicaragua, we demonstrate the applicability of this approach to: i) estimate/quantify POCs; ii) assess environmental and socio-economic additionality of the PES initiative in question; and iii) quantify the information rents harvested by participants. Apart from adding to the limited empirical studies of detailed POC and efficiency loss due to private information rents in PES, our contribution is a better understanding of the intra-household/on-farm trade-offs, which may result from PES participation, and hence a better future basis for PES policy design.

2 Methodology and model formulation

2.1 Study area

The study area, four communities in El Castillo Municipality in the Department of San Carlos, Río San Juan, Nicaragua, is characterised by high incidence of poverty, illiteracy and inaccessibility. UNDP (2009) categorize 64,6% of Nicaragua's rural population as 'poor' (figures for 2005), and of El Castillo's population of app. 22,000 persons 65.7% are classified by Nicaragua's National Institute of Information on Development (INIDE 2008) as extremely poor. The Human Development Index for the Municipality is one of the lowest in Nicaragua (0.486) and illiteracy among adults as high as 59% (UNDP, 2003). This is also reflected in infrastructure, health and educational services in the region that are poorly developed. None of the communities in the study area have access to electricity or potable water. Primary school is within reach for most, but often with ½-1 hours walking distance from farms, and health services and point of sales for agricultural products are often 1-3 hours away (one way). Transportation is by foot or beast via muddy tracks used by cattle and man alike, and often implies crossing rivers by foot or improvised bridges. All farm work is done by manual labour only and there were no cases of purchased fertilizer or pesticide input to production. Individual community size ranges between 40 and 70 families. The pilot PES scheme ran from 2007-09 and was implemented by Fundación del Río (FdR), a local environmental NGO. The programme paid a yearly sum of US$ 30/ha/year for forest conservation, payments were made once a year contingent upon inspection of intact forest area compared to a

2006 baseline for each of the 12 participating farms. Eligibility criteria for programme participation were: i) positive conservation attitude; ii) location in one of four target communities adjacent to a protected area; iii) secure tenure; and iv) presence of intact primary forest on the farm. The programme further stipulated the enrolment of minimum 10 ha of forest and a maximum of 28 ha/farm, and obliged participants to apply for Private Forest Reserve (PFR) status with MARENA.

2.2 Data collection

Data collection focused on economic factors likely to affect a HH's desire to participate in a PES programme, primarily factors related to opportunity costs through current farming practices, HH strategies and the exogenous product and labour market. A wide selection of quantitative and qualitative data was collected in 2009 during fieldwork in El Castillo Municipality. 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 included 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; and iv) crop production; and v) livestock production, including production and labour input. Summary data used in the present analysis are presented in Annexes C.

Following Thomas (2004), cited in Arriagada et al. (2009), an explanatory approach has been adopted based on structured field interviews with the group of PES-participants (12 HHs, 100% of PES participants) and a control group of non-participants from the same four PES-target communities (20 HHs out of which 2 have forest areas less than the 10 ha minimum limit). Interviews followed participatory econometrics approach (Rao & Woolcock, 2003; Swann, 2006), where follow-up interviews have been made to clarify issues and resolve anomalies.

2.3 General data analysis

The quantitative part of the interview questions, including data quality control questions, have been structured and formulated based on a simple household income model (hypothesis of linkages), on the a priori assumption that HH income and income sources plays an important role in HH livelihood decisions. Relevant data was extracted from the case study database and used to: i) estimate model parameters, and ii) qualitatively support or negate results of model estimation and simulation. Following Pagiola et al. (2008), we have used HH income data to classify HHs into one of three groups using the poverty limits given in World Bank (2003). Those HHs with per capita incomes below the extreme poverty limit (0.55 usd/cap/day) are "extremely poor", those above the poverty limit (1.10 usd/cap/day) are "non-poor" and those in between are classified as "poor".

2.4 Data analysis and POC estimation framework

In order to estimate and quantify opportunity costs and likely livelihood and land use consequences of PES enrolment for poor farmers in El Castillo, we employ a simple agriculture income model framework. Our model approach builds on the theoretical approach used by Alix-Garcia et al. (2010), which in turn is based on standard agricultural household models described by e.g. Singh et al. (1986), and employed by e.g. Taylor & Adelman (2002) and Howitt (2005). Alix-Garcia et al. (2010) have used such a household model to theoretically analyse the potential changes in production behaviour induced by a conservation payment scheme, and their economic model framework incorporates the following parameters: forest use, agricultural production (all-in-one), and capital and credit availability to farmers. With the purpose of making a more operational model linking theory and practice, as called for by Pattanayak, Wunder & Ferraro (2010), we i) simplify the basic structure of the Alix-Garcia et al. model by assuming linear and unit-true production functions; and ii) fit the model to the particular settings in El Castillo by further sub-dividing 'agricultural production' into three different production systems with each their production function (livestock, crops and fallow/rotational area) in addition to forest use and PES. Also, as farmers in El Castillo have extremely limited access to credit (no bank or credit institutions are present) and none had savings before PES, we thus initially omit this compared to Alix-Garcia et al. (2010). However, introduction of PES under such conditions may ease this capital constraint and a secondary effect of PES may occur as HHs incorporate this option. A capital constraint variable is therefore introduced in a second step of model development to simulate consequences of easing such an initial, implicit constraint. The relevance of this is underscored by the cost of conversion from one land use, which is reflected in the fact that cleared agricultural land in the area costs up to three times as much as forested land. A capital constraint may thus be decisive in whether such a conversion takes place, regardless of year-to-year profitability. Hence, given data on HH size, present land-use distribution, key farming parameters (<u>p</u>rices, <u>y</u>ield, <u>e</u>ffectiveness of both crop and livestock) and labour market data, we maximize HH income X_a from farm work (any income from non-farm work, X_e, is added to the farm income to give the total HH income X_t):

$$\max_{A_p, A_f, A_c, A_l} X_t = X_e + p_p A_p + p_f y_f A_f + r_s p_c y_c A_c + r_s p_l D_c y_c A_l + f_o w L_o - w L_h \qquad (1)$$

subject to the following land (1-3), labour (4) and capital (5) constraints:

1. $A_p + A_f + A_c + A_l + A_r = A_{tot}$
2. $A_p + A_f \leq A_{of}$
3. $A_c + A_l \geq A_s$

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

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

A list of all variables and parameters used in the HH income model are given in Annex A and the model is described in more detail in Annex B.

Family farm labour as a constraint on land use choices was up-front expected to be the most significant decision variable since farms in the study area are relatively large (average farm size is 88 ha in the PES group and 33 ha in the control group). Available family farm labour in turn interacts with external labour markets and related wages. For inspiration on how to incorporate this, we turned to Chen (2009), who presents a theoretical analysis of how off-farm labour market imperfection may impact the efficiency of a PES-program for landowners.

3 RESULTS

3.1 Basic HH characteristics

The PES recipient group and the control group were insignificantly different on all examined aspects of HH and land use characteristics, i.e. human and natural assets, except for the amount of labour allocated to work on own farm, L_a, see Figure 1 and Annex C for details.

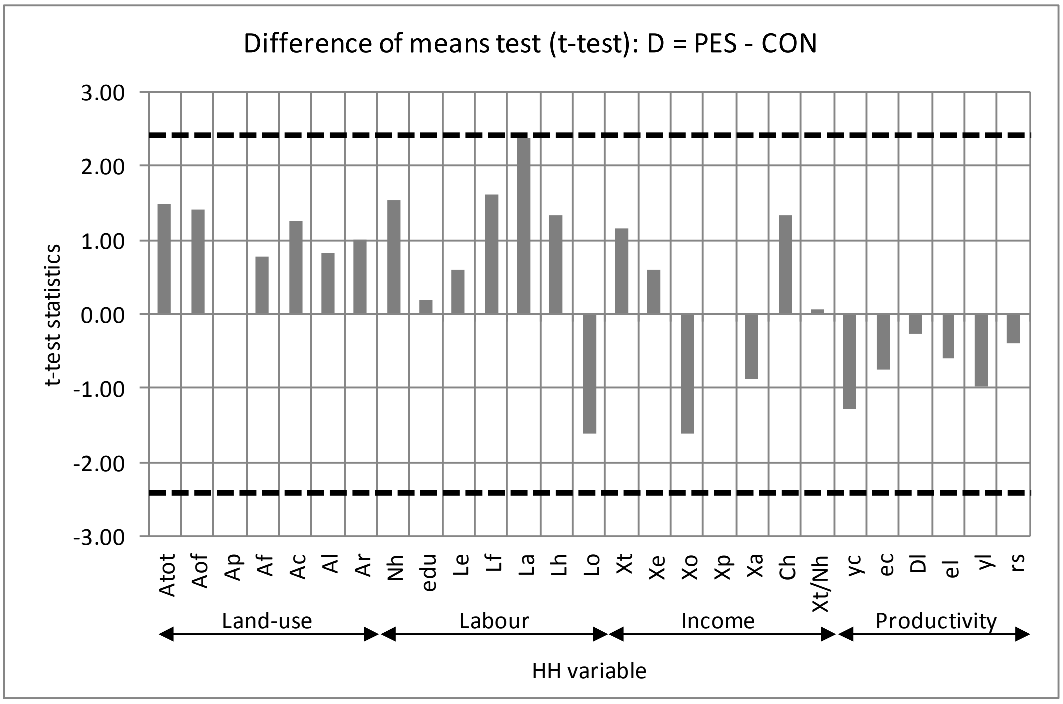

Figure 1: Student t-test of differences between means of observed key PES and CON-group characteristics. Dashed lines mark the average confidence limits. Variable names are defined in Annex A.

Certain differences were discernible, nevertheless, primarily related to total farm size, although this was skewed by one large farm (482 ha) in the PES group. Without it, average farm size for the PES group drops to 52 ha. A second observable difference is naturally the forest area under PES contract, as well as the total forest area. This latter figure is considerably influenced too, though, by the same PES participant with a predominantly forest covered farm of 482 ha.

Based on per capita income PES and control group respondents have been categorised according to poverty level, adopting the definitions in Pagiola et al. (2008), see Figure 2.

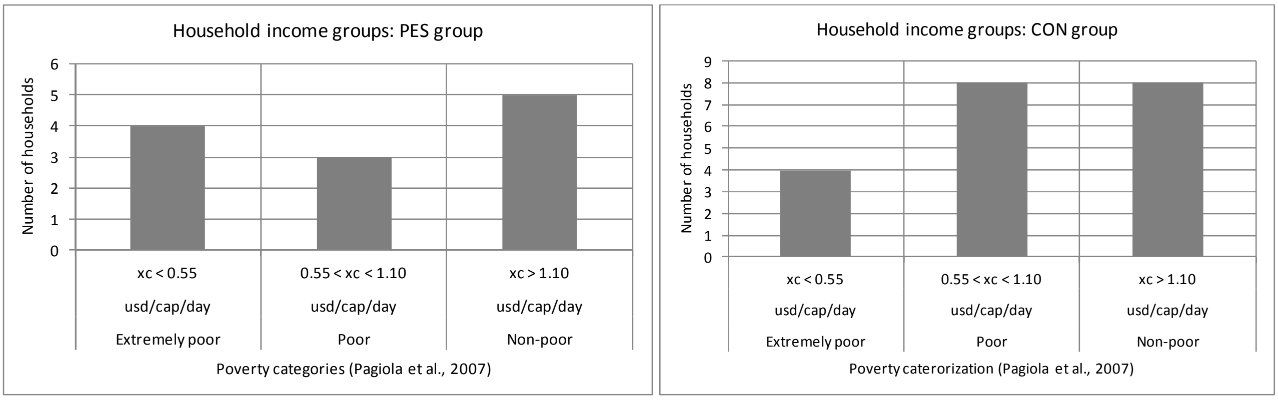

Figure 2: Household distribution in poverty categories according to Pagiola et al. (2008). xc is total net per capita income per day.

Although average total income is higher in the PES group, the percentage of *Extremely Poor* is also higher in the PES-group (4/12 compared to 4/20 in the CON group), which is to say that the income variation is larger in PES group compared to the CON group. The share of *Non-poor* is comparable in the two groups (5/12 compared to 8/20). The major difference in income and income distribution between the two groups is the PES payment and the non-farm income. Average income in PES-households is higher and comes mainly from PES-payments and non-farm work, whereas income in the CON-group is more or less evenly distributed between non-farm work, off-farm work and own agricultural production. Income from farm work (own-farm and off-farm) is higher in the CON-group than in the PES-group.

The labour distribution in the two groups is roughly identical; however, one significant difference being that HHs in the PES group on average dispose over more total available farm labour time as a consequence of larger average HH size. The farming productivity in the CON-group is on all parameters higher, but not significantly so, and the higher production compensate the lesser labour input to achieve the higher farm income compared to the PES-group.

3.2 Poverty and benefits from PES

Over the last decade PES has increasingly been seen as an instrument that can provide not only ES but also alleviate poverty in developing countries. While it is true that all case study HHs are poor (per-capita income < 3 usd/cap/day), as is generally the case in rural areas in developing countries, some are extremely poor as presented in section 3.1. The question is whether extremely poor HHs can be expected to benefit more from PES-programs than non-poor HHs. To answer this question, we have employed the HH income maximization model to predict how the land-use and income would change if: i) the CON-group HHs were to be offered participation in a PES-program; and ii) the PES-program would end and the PES-group HHs subsequently loose the PES-income. The latter simulation assumes that HH decisions are based on present with-PES conditions, which may have improved (investment in farm improvement and/or in alternative non-farm income) as a consequence of the PES-payments they have already received. The results of the two simulation scenarios are presented in Figure 3.

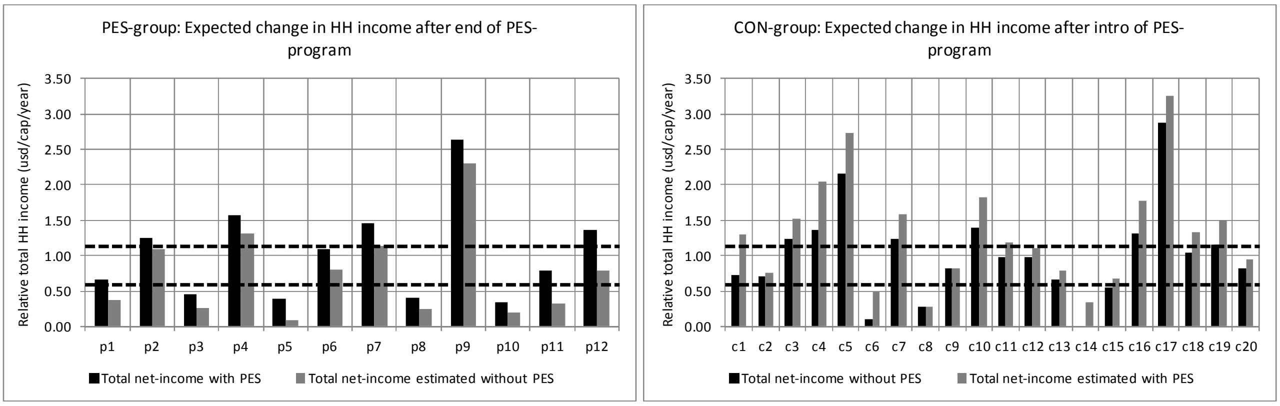

Figure 3: Simulated change in HH income (usd/cap/day) as a result of the hypothetical situations: i) end of the PES-program for the PES-group (left panel), and ii) introduction of a PES-program for the CON-group (left panel). The dash lines mark the limits between poverty categories according to Pagiola et al. (2008).

The simulations show that in the PES-group, two HHs presently in the "poor" category (p1, p11) will drop from the "poor" to the "extremely poor" category. Out of the five HHs presently in the "non-poor" category, one will drop to the "poor" category and two balance on the limit between the two categories. In the CON-group, it is expected that all HHs would participate in a hypothetical extension of the PES-program (p_p = 30 usd/ha, 10ha $\leq A_p \leq$ 28.2ha), however, four participants are expected to enrol less than the eligible forest area (60% - 90%). One (c15) out of the four "extremely poor" HHs will only just advance to the "poor" category, although the two poorest HHs (c6 and c14) will experience a very high relative income increase. Five HHs in the "poor" category will advance to the "non-poor" category.

If we look at the distribution of the total PES-payments over the poverty categories, we find that in the present PES-group payments (~ 7,500 usd/year, 251 ha) are roughly evenly distributed over the three categories (extremely poor: 29%, poor: 34%, non-poor: 37%). In the hypothetical case where the CON-group were to be invited to participate in the PES-program, it is expected that

21% of the total payments (~ 9,000 usd/year for 300 ha) will go to the "extremely poor" category HHs, 29% to the "poor" and 50% to the "non-poor".

3.3 Estimation of model variables/parameters and calculation of POCs

Model parameters are estimated for each HH in the two groups, based on the empirical data collected and compared (Table 1). In both groups some HHs have only crop or livestock, and in the CON-group, three HHs do not have any agricultural production whatsoever.

Variable	PES group	CON group
y_c (kg/ha)	N_{obs}=12	N_{obs} =17
mean	687	648
standard deviation	220	175
e_c (ha/person)	N_{obs} =12	N_{obs} =17
mean	1.49	1.68
standard deviation	0.72	0.63
y_l (% of stock)	N_{obs} =9	N_{obs} =12
mean	0.26	0.25
standard deviation	0.13	0.08
e_l (heads/person)	N_{obs} =9	N_{obs} =12
mean	40	46
standard deviation	31	20
D_l (heads/ha)	N_{obs} =9	N_{obs} =12
mean	1.19	1.26
standard deviation	0.76	0.48
r_s (%)	N_{obs} =12	N_{obs} =20
mean	0.30	0.34
standard deviation	0.31	0.35

Table 1: Results of model parameter estimation for the PES and control groups. The graphs show the distribution of observed key HH parameters (dots) and fitted theoretical probability distributions.

The variations in each of the estimated parameter values between participants in each the two groups are larger than the difference between the parameter mean values, which confirms the similarity of the basic conditions. The estimated parameter values for y_c, y_l and cattle density obtained, as well as produce prices, have been checked against statistics from the Food and Agricultural Organisation (FAO) from 2009 for Nicaragua and found in good correspondence with these, further lending support to their value, despite being a momentary snapshot only.

Having obtained the key production parameters, we can calculate the marginal income from various land-uses and subsequently the opportunity cost ratios between the available land-use and labour alternatives. The per-hectare unconstrained marginal incomes (usd/ha) are calculated as follows:

$$\begin{aligned} MI_p &= p_p \\ MI_f &= p_f y_f \\ MI_c &= r_s p_c y_c - f_o w / e_c \\ MI_l &= r_s p_l y_l - f_o w D_l / e_l \end{aligned} \qquad (2)$$

The marginal income from PES (p_p = 30 usd/ha/year for the PES group and 0 for the CON-group) and forest are considered constant for all HHs ($p_f y_f$ ~ 10 usd/ha/year based on information from interviews). Hence, the opportunity cost ratio between PES and ordinary HH forest production is 3. Table 2 presents the unconstrained marginal income from crop production and livestock production using eq. 2, and the respective unconstrained opportunity cost ratios relative to the PES-payment, i.e. a positive opportunity cost ratio in this case indicates the economic superiority of crops cultivated or livestock rearing over PES.

Participant	MI_c (usd/ha/year)	MI_l (usd/ha/year)	**Opportunity cost ratio OC(c, p)**	**Opportunity cost ratio OC(l, p)**
p1	-677	-60	-22.6	-2.0
p2	44	2.8	1.5	0.1
p3	-288	3.2	-9.6	0.1
p4	-13	No livestock	-0.4	0.0
p5	-164	-6.2	-5.5	-0.2
p6	-273	No livestock	-9.1	0.0
p7	193	7.6	6.4	0.3
p8	-101	1.1	-3.4	0.0
p9	-278	-15	-9.3	-0.5
p10	-197	-5.4	-6.6	-0.2
p11	-72	22	-2.4	0.7
p12	-437	No livestock	-14.6	0.0

Table 2: Calculation of PES-participants' unconstrained marginal incomes and opportunity cost ratios for f_o = 50%.

It is seen that only p2 and p7 seem able to increase farm-generated income by expanding the crop area (column 2 in Table 2). For the rest of the PES-participants, there is no real competition between PES-payment and income from agricultural production – unless the possibility of getting off-farm work is zero, and therefore also the farm labour opportunity cost. The calculated opportunity costs are consistent with the actual, observed choices by participants as to how much of the eligible PES-area is enrolled in the PES-program. Figure 4 illustrates the actual relative (actual/eligible) enrolled PES-area as a function of the marginal income from farm production. As can be seen the majority of HHs with negative marginal income from agricultural activities have enrolled all of their eligible forest area under a PES contract.

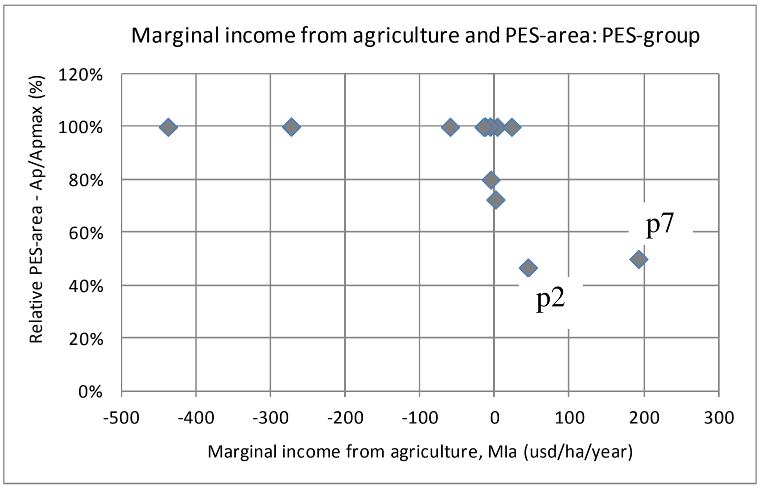

Figure 4: Relationship between unconstrained marginal income from agriculture ($MI_a = max(MI_c, MI_l)$) and the relative enrolled PES area (A_p/A_p^{max}).

Four participants have chosen not to enrol all eligible forest area and two of these as little as approximately 50%. These two HHs are the most effective farmers (high e_c and e_l-values), who as long as they have surplus family farm labour, or can hire external labour that is equally effective, can generate more income than the PES-payment can provide. A PES payment of 30 usd/ha/year would thus not be able to compete with agricultural production for these two HHs. Table 3 presents the marginal income from crop and livestock production for the CON-group, and the respective opportunity costs relative to a possible PES-payment of 30 usd/ha/year.

Participant	MI_c (usd/ha/year)	MI_l (usd/ha/year)	**Opportunity cost ratio OC(c, p)**	**Opportunity cost ratio OC(l, p)**
c1	-10	3	-0.3	0.1
c2	-366	-18	-12.2	-0.6
c3	-112	25	-3.7	0.8
c4	96	6	3.2	0.2
c5	103	26	3.4	0.9
c6	-199	No livestock	-6.6	0.0
c7	38	-1	1.3	0.0
c8	-212	No livestock	-7.1	0.0
c9	123	34	4.1	1.1
c10	-99	-7	-3.3	-0.2
c11	-166	No livestock	-5.5	0.0
c12	No crops	No livestock	0.0	0.0
c13	-28	15	-0.9	0.5
c14	-373	No livestock	-12.4	0.0
c15	216	7	7.2	0.2
c16	78	26	2.6	0.9
c17	No crops	No livestock	0.0	0.0
c18	14	8	0.5	0.3
c19	No crops	No livestock	0.0	0.0
c20	-95	No livestock	-3.2	0.0

Table 3: Calculation of CON-participants' unconstrained marginal incomes and opportunity cost ratios.

In the CON-group, 7 participants show positive marginal income of agricultural production (shaded rows). This is a result of higher values for crop and livestock productivity and cattle density. Out of the 7 HHs, 6 show a crop/PES opportunity cost ratio higher than 1, suggesting that these HHs (c4, c5, c7, c9, c15, c16) will not benefit from a PES-program, unless labour constraints (or capital ditto) prevent inclusion of additional land under agricultural production.

3.4 Test and application of the HH income maximization model (HIM)

3.4.1 Test of parameter robustness using HH-data from the RISEMP project in Nicaragua

In order to test the validity of input data and estimated parameters from the case study for other areas of Nicaragua and the overall ability of the model to estimate a HH's income, we have used a completely unrelated data set collected in a comprehensive PES study in the Matiguás-Río Blanco area in Nicaragua reported in Pagiola et al. (2008). The RISEMP data set contains the relevant input (household and land) parameters needed in the HIM, and model outputs consistent with observed total income in the RISEMP/Nicaragua study will thus support the general validity of the model structure and basic input data, making it more likely that no significant sources of income have been overlooked or ignored when looking at rural Nicaragua.

Pagiola et al. (2008) examine the extent to which eligible poorer HHs are in fact able to participate in the RISEMP project. For this purpose farm and HH data were collected from 103 HHs. Using the average key family and land use data provided by Pagiola *et al.*'s study as input (shaded cells in Table 4), the HIM model calculates the production functions (including the number of cattle) and the expected HH net income, both of which are among the key data gathered in the Pagiola-study. The income-part of the HIM calculates that the average family from the RISEMP project can produce some 6 heads/year, which is equal to the average livestock production factor, y_l (= 26%), times the total stock. The total stock is thus calculated to 24-25 heads of cattle, which compares relatively well with the 30 heads found in the RISEMP study (Table 4).

Our model estimates a total HH net income of 2,096 usd/year for the average family in Pagiola's study (household size of 6 persons) giving a per capita net income of 349 usd/cap/year for the average family (= 4,979 cordobas/cap/year using an exchange rate of 20 cordobas/usd). Pagiola et al. (2008) report a net income of 4,675 cordobas/cap/year for the average family. We can therefore conclude that employing prices and the estimated HIM parameters based on the information from the PES participants in El Castillo, lead to income estimation results that are consistent with the reported HH incomes in the participant-wise more comprehensive study by Pagiola et al. (2008). This supports the robustness of our household model and its potential useful application in other rural areas of Nicaragua.

Input data and calculations	Variable	Unit	Value
Household labour state variables			
Household size	N_h	cap	6
Number of children	N_c	cap	4
Number of adults	N_a	cap	2
Effective full-time persons for farm work	L_t	cap	3.0
Persons available for non-farm work	L_e	cap	0.5
Labour available for farm work	L_f	cap	2.5
Labour required to cultivate farm	L_a	cap	2.0
Hired farm labour	L_h	cap	0.0
Off-farm work	L_o	cap	0.3
Land use data			
Total area	A_{tot}	ha	30.7
Original forest area	A_{of}	ha	7.8
PES area	A_p	ha	2.8
Forest area in addition to PES area	A_f	ha	5.1
Crop area	A_c	ha	2.0
Pasture for livestock	A_l	ha	20.8
Production estimates			
PES	q_p	ha	2.8
Crops	q_c	kg	1,374
Livestock	q_l	heads	6
Forest	q_f	no of trees	0.5
Income distribution			
PES	X_p	usd/year	84
Crops	X_c	usd/year	308
Livestock	X_l	usd/year	354
Forest	X_f	usd/year	26
Off-farm work	X_o	usd/year	227
Non-farm work	X_e	usd/year	1,098
Total household net income	X_t	usd/year	*2,096*

Table 4: Household model net income estimation using the average family/farm data (shaded cells) from Pagiola et al. (2008) as input. Data are extracted from tables 2 and 3 in the paper.

3.4.2 Application of the HIM to analyse the effect of changes in contextual factors

Section 3.2 gave us an idea of the short-term income change as a result of a hypothetical introduction of a PES intervention to the CON-group may have had using the estimated parameters and calculated opportunity costs under the given constraints in family farm labour and land. A look at the qualitative information from field work, however, revealed another interesting and natural aspect: that some PES recipients had re-invested payments in agricultural production, leading to increases in production (e.g. purchase of additional livestock or cash crop seedlings). They credited the PES programme with enabling them to do so, and this made it relevant to look at the potential secondary effect of payments as easing a capital constraint. It was evident from field work that payments were invested very differently from HH to HH, but looking at the longer term environmental impact of the PES influx of cash is very relevant from a PES policy perspective.

Now, the equations to calculate unconstrained opportunity costs illustrate the importance of the likelihood, wages and preference for off-farm work in determining POC. In the following we therefore also investigate the influence of the existence or absence of such a labour market for off-farm work via the extreme case of no off-farm work to be had and alternatively a scenario where off-farm work is available/economically preferred at the estimated f_o for the CON-group (88%). Using the CON-group as guinea pigs, with the estimated model parameters for the CON-group, the HIM is used to simulate the economically optimal land use distribution for each HH by maximizing HH income if PES were made an option, and given the actual labour and cash constraints. In these scenarios we cannot reasonably predict whether introduction of PES will alter preferences and eventually job availability, but contain ourselves to assuming it constant between *ex ante* and *ex-post*. We look at three scenarios to investigate how environmental (land-use distribution) and socio-economic impact (HH income) varies with varying access to capital (whether own or credit) and frequency of off-farm labour (whether determined by availability or preference) in a situation where PES is an option. Also, we assume that no additional capital is available except that provided in the form of PES. The three scenarios are:

1. Offering PES to the CON-group with no re-investment of PES and the current off-farm labour market (f_o = 88%);
2. Investment of all PES income ($C = X_p = p_p A_p$) and an off-farm labour market exists; and
3. Offering PES to the CON-group with re-investment of all PES income; no off-farm labour market exists (f_o = 0%).

The group average results are presented in Figure 5 to illustrate the overall tendencies (differences between scenarios) and detailed HH results can be found in Annex D.

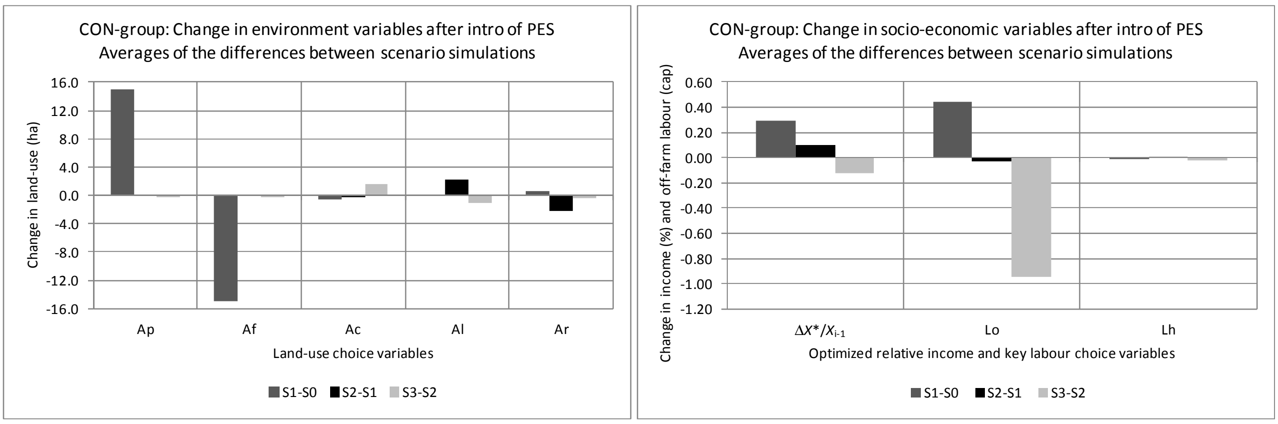

Figure 5: Environmental and socio-economic effects of changes in cash income and off-farm labour market frequency

Not surprisingly, introduction of PES (S1 compared to present S0) leads to the largest change in land-use were on average approximately 15 ha/HH of forest are converted to PES-area. A minor reduction of crop area and increase of livestock and fallow area can be expected. Allowing HHs to invest in farm improvement/expansion all cash income from the PES-area (S2 compared to S1) they choose to enrol, results in an increase of livestock area mainly by converting fallow area. If off-farm labour market frequency is reduced to zero, this effect will be more or less reversed: livestock area is likely to be converted to crop area. One HH (c11) is expected to convert 2 ha of PES-area to crop area; otherwise, all HHs are expected to maintain the chosen PES-areas.

Participation in a PES-program is expected to increase the group average income by some 30%; however, with large variations within the group. Introducing cash income for farm improvement will on average increase the HH income by another 10% (S2 compared to S1), i.e. a total increase in income of 42% (S2 compared to S0). In the case of zero off-farm labour market frequency, the group average income is reduced by 10% (S3 compared to S2). Hired labour is not used frequently by HHs, only 2% of the total income is spent on paid external labour, and no changes in that pattern is expected. Off-farm labour, on the other hand, is obviously affected by preferences and available off-farm labour market. Given the present situation, participation in a PES-program will on average increase the amount of off-farm labour. This trend, however, is the result of 4-5 less-productive HHs who chose to abandon a portion of their crop area and use the freed labour for livestock rearing and off-farm work. If off-farm work frequency is zero, the opposite happens: crop and/or livestock production, dependent on productivity, is increased.

4 DISCUSSION

4.1 Basic results

The number of respondents in the case study constitutes a weakness. Apart from resource constraints related to in-depth case studies, the number was physically limited by the modest number of total PES participants (*N*=12). We have no immediate idea of cause and effect, when it comes to explaining the difference between the observed labour allocations towards non-farm work in the two groups for lack of a baseline. The higher income from non-farm work in the PES group may theoretically be either an effect (they now have money from PES to invest in chain saws, kiosk establishment etc., which are more profitable occupations), or a cause for joining PES in the sense that opportunity costs are low, since they get their main income from other sources and less people are hence left to manage farms, decreasing total income from agricultural activities. Qualitative interview results indicate a stronger probability of the former, but as numbers are modest it would be folly to conclude anything from it. In general, labour allocation in the present optimization model formulation is considered as explicit choice variables together with land-use distribution, which is too simplified an approach. Subsequent interviews have revealed that HHs tend to prioritize/allocate labour resources – conditioned on educational level, capital and off-farm market potential – and then to allocate/optimize land-use according to available own-farm labour resources. Such a more realistic and detailed HH labour allocation model is under development and will be presented in a subsequent paper.

Poverty status appears to have little influence on PES-participation, and vice versa. Clearly PES contributes an added income to all HHs regardless of pre-PES poverty status. In El Castillo, we find that payments to the PES-group are largely equally distributed over the three poverty categories, however, with the non-poor receiving 37% and the extremely poor receiving 29% of the total annual budget. Using the HIM to simulate the effect of the CON-group being invited to participate in the current PES-program, shows that it can be expected that up to 50% of the total budget will be directed to the non-poor category. Furthermore, it is to be expected that movements between the poverty categories are minimal.

4.2 Private opportunity costs

Only few studies have considered secondary effects of PES introduction, e.g. down the value chain as a consequence of forest conservation as opposed to forest exploitation (Wunder, 2007) or impact of PES on HH and land use distribution as a consequence of access to additional capital (Alix-Garcia *et al.* 2010). Alix-Garcia *et al.* demonstrated the theoretical risk of on-farm slippage through substitution as a result of increased access to capital (incl. PES cash), consistent with what our simple HH income model indicates as a risk under no access to off-farm labour, supporting the importance of investigating secondary effects of PES introduction.

Unconstrained private opportunity costs are generated at the interface between HH and surrounding society, varying as they do with output prices, labour market access/availability and wage levels. Where PES literature normally stops at the hierarchy of POCs, listing the most profitable, realistic alternative land use as the foregone income, the inclusion of foregone earnings from paid off-farm work as a measure of the value of family farm labour input to production gives a more thorough picture of the actual, realised opportunity costs. This means that the local labour market is indeed important for POC, influencing POC via wage levels, labour demand and farming effectiveness, and with potential to change the economic ranking of paid work versus agricultural activities and hence the land use and environmental impacts of a PES programme.

Household opportunity costs in the present study are highly individual and vary with farming yield, ability to sell products, off-farm labour wages and opportunity and farming effectiveness. Calculated unconstrained POCs also indicate likelihood of participation in a PES-program: those

HHs in the PES-group with the highest POCs have enrolled less that their eligible forest area in the PES-program. We propose that further research should be done into how constrained POCs interact with land-use competition and how these linkages can be quantified and used for assessment of program participation, additionality and efficiency.

4.3 Model simulations

4.3.1 Model robustness

The margin within which the model seems able to simulate total income for a completely unrelated data set, based on relatively basic input and the parameters estimated from the case study field work indicates a reasonable robustness. We thus feel reassured that no major income sources have been overlooked and that produce prices used in this study are representative. It is regrettable, however, that no project baseline was conducted, as this would have allowed us to check the predictive power of the model to a better extent, as well as judge better if the larger share of non-farm work among PES respondents were a cause, effect or non-related to the PES programme introduction. A relative weakness of the model is that we cannot properly discern causes of labour frequency (f_o): it may theoretically be preference as well as labour demand that ultimately determines our f_o. To the extent such a labour frequency can be estimated directly from HH sampling, it does seem sufficient to describe realities and arrive at robust estimates of total HH income. The latter subject (preference) reminds us that despite what seems a demonstrated predominantly economic motive for behavioural patterns, obviously other motives may influence allocation of land and labour. Model results seem to indicate that such motives are not large compared to economic motives, though.

In terms of HH characteristics the rural population of El Castillo is relatively homogenous, and the HIM in its present version is likely to be most applicable in such circumstances. Under conditions where the target population is very diverse it may be relevant to divide it into sub-groups, to facilitate simulation of how PES may impact different e.g. income groups, HHs of particular livelihood strategies, wide variety in the production systems etc. The model itself may be consulted for indications of which terms (corresponding to actual, physical states) are relevant to consider. All parameters and terms of the HIM have direct and intuitive links to reality, enabling measurement, estimation and verification, so that the model may be calibrated and adjusted to different appropriate settings.

The HIM builds on assumptions of predominantly economic motivation for land and labour use decisions hold, and the ability of farmers to recognise their costs and benefits from the various uses. The former is indicated by the comparison of calculated total HH income compared to observed income, and the latter is indicated by the comparison of calculated optimal land use to actual land use. Assuming confidence in these assumptions the model is able to provide an estimate of overall trends in PES impact, that is, a net environmental and socio-economic impact across the target group and area. This leaves us with the problem of ensuring sufficient representativeness of a possible sample to the whole of a potential target population. This may be achieved by: i) sheer sample size, or ii) by examining combinations of HH characteristics likely impacted differently by PES, labour market conditions and prices. Given that the present model formulation requires numerical solution of the income maximization function for each HH, the first approach is time consuming and not practical/feasible for policy and planning purposes. Next step is, therefore, to develop a closed-form analytical solution that can explicitly model the environmental and economic effects of changes in intra-HH and external contextual factors.

4.3.2 Simulations using the CON-group as test HHs

The HIM is obviously a momentary snap-shot of a situation in terms of particularly contextual factors such as prices and wage levels, this does not, however, alter the general validity of the model as such. We have not dealt explicitly with the importance of potential changes in agricultural output prices here, nor in wages associated with off-farm work, but from the model structure and terms it is obvious that prices and wages determine opportunity costs and thus have the potential to shift balances between land uses and between agriculture and off-farm labour. The HIM can, however, also be used for exactly this – simulating changes in e.g. livestock or crop prices to assess the possible influence this might have on POC and land use distribution at different PES rates, labour market conditions, etc. The latter is illustrated by our exercise in scenario 3 where we simulate collapse/absence of a local off-farm labour market, demonstrating how a clear trend towards intensification of agriculture results as a consequence of zero foregone income from off-farm labour.

Looking at the secondary effects of the cash infusion (scenario 2) PES may possibly constitute in a previously capital constrained community/area, we have for simplicity's sake only looked at reinvestment in agricultural activities. That this is a simplification is already obvious from field work, where it was observed that a few HHs had invested payments in establishing non-farm income-generating activities or micro-businesses. Assuming this is also a rational economic choice by HHs, it would imply that we underestimate the socio-economic benefit of the PES intervention. This also means that in both scenario 2 and 3 we simulate 'worst case scenarios' where habitat conservation is concerned. We could with more PES participants have made a more reliable mapping and perhaps estimated the proportion of payments reinvested in agricultural production to limit the uncertainty when choosing a realistic scenario to simulate. Likewise, any non-pecuniary benefits are ignored by the HIM. That they exist is demonstrated by information from PES-participants, who report having used funds to send children off to secondary school, medical care and to mitigate external shocks. The outcomes of the three scenario simulations are discussed in the following.

Scenario 1: Offering PES to the CON-group with no re-investment of PES; an off-farm labour market exists

The socio-economic result of the first scenario compared to the 'without PES-situation' is that the majority of HHs (15 out of 18 – c7 and c8 do not have enough eligible forest to participate) could increase their net income by more than 5%. For some, PES would provide a rather large increase in HH income (Annex D, Table D.1). Four HHs would benefit in particular. These are the HHs with practically no income from farming activities. HHs c6 and c14 are the poorest HHs in the group (although not the least productive farmers), whereas c19 has no agricultural activities and c3 is the least productive crop farmer but the most productive livestock farmer. In terms of livelihood strategies the scenario points to an increased attractiveness of off-farm work at the expense of intensive farming practices. The environmental result of the first scenario is also evident from Table D.1: the environmental additionality is minimal, and modest changes take place between other agricultural land uses in the direction of less intensive crop cultivation.

Scenario 2: Re-investment of all PES income and an off-farm labour market exists

Relative to scenario 1, scenario 2 changes only the amount available for investment in the productive capacity of the farm, and assumes that 100% of PES income is invested thus. Given observed uses of PES funds received, a realistic scenario is somewhere in between the two extremes. Frequency of off-farm labour is set as in scenario 1. As seen from Annex D (Table D.2), reinvesting PES cash would for the majority further increase HH income, on average by 12%. The average covers a wide variation, though, from 0% to 95% potential 'extra' increase in economic benefit from PES by reinvesting. Livelihood strategies run towards further extensification, primarily converting fallow land, but in a few cases also crop land. Three of the four HHs, who stood to gain most from PES participation in scenario 1, are again seen to gain relatively more from reinvesting PES. One of the absolute poorest HHs (c6: plenty of forest, no livestock) stands to further increase income by 64% by switching from crops to livestock and increasing frequency of off-farm work with the freed-up labour. The latter obviously still assuming such work is to be had as per our previously mentioned reservations. The high jumper, HH c14, is another of the poorest HHs. They only cultivate a small area on which they have the lowest productivity in the CON-group, but have a large area of forest intact. Reinvesting PES money in livestock would bring about a significant additional income (95%) compared to not reinvesting.

Finally, c19 has a lot of forest, but no agricultural production. They do have one person engaged full time in well-paid non-farm work, though. Here, HH income could potentially increase by 9% by diverting off-farm labour to own farm and increasing agricultural production in the form of both crop cultivation and livestock rearing. Under scenario 2, HHs will generally choose to invest in livestock in order to maximise income. The main trend is that fallow area is converted into livestock area, meaning total livestock area is significantly increased. A few HHs will convert crop land to livestock area. Off-farm work is generally maintained at the pre-PES present level.

Scenario 3: Offering PES to the CON-group with re-investment of all PES income; no off-farm labour market exists

Changing scenario 2 by setting off-farm labour frequency to zero gives us scenario 3. If the local labour market disappears (or wages drop dramatically, both conditions eliminating the need to know if f_o is preference or availability) and HHs are assumed to invest all PES-related income in raising farm production, all available labour will be utilised on own farm since no other immediate income-generating alternative exists. Since working one's own farm now carries no opportunity cost *vis-a-vis* non-existing off-farm labour, all family labour is directed to whatever farm-based activities maximising HH income. This is predominantly crop production, which despite being a lot more labour intensive, also generates a relatively larger return on invested man-power. The HHs mostly affected and unable to compensate sufficiently income-wise for the collapse of a local labour market are naturally enough among those most dependent on non-farm and off-farm work beforehand, generally reflecting that paid work is more attractive than cultivating one's own farm when: i) the family's subsistence needs have been met; and/or ii) farming productivity is low. A fair amount of HHs with an originally predominant reliance on agriculture for income (and subsistence) is predicted by the simulation to be only modestly affected by 'collapse' of a local off-farm labour market, if at all. It is a possible explanation that this is so, because of exactly their lack of initial access to or preference for off-farm work.

Even without the re-investment of PES-capital in farming, the lack of a local off-farm labour market combined with PES will lead to an intensification of agriculture, meaning inclusion of fallow areas in active agriculture and a prominent change towards relatively more intense cropping at the expense of livestock rearing. One HH, c11, characterised by a high proportion of forest (12.7 ha) on a relatively modest sized farm (16.2 ha) and no livestock production, is seen to find it attractive to even take down forest to establish crops, indicating that had the average A_f/A_{tot} ratio been larger and even combined with ample family farm labour supply this might have been a more common occurrence.

4.4 POC as a measure of cost-effectiveness (size of private information rents)

The private information rent is here defined as the difference between what is paid to HHs in El Castillo using a flat rate (30 usd/ha) and the estimated unconstrained opportunity cost equal to the best alternative land-use. The efficiency of the current PES-program can thus be estimated using the unconstrained POCs in Table 2 to calculate for each of the 12 HHs the best alternative marginal income ($\max(MI_c, MI_l)$), subtract the PES-payment, multiply by the PES-area and sum over the total number of HHs. The total area protected under the current PES-program is 251 ha and the total cost is approximately 7,500 usd/year. If HHs were to be paid only the POC of the best alternative, the total payment would reduce to approximately 3,350 usd/year, which gives an overall efficiency of 45%. This estimate is based on unconstrained POCs and since constrained POCs are ≤ unconstrained POCs, we must therefore expect that the overall program efficiency is less than 45%.

Unconstrained POCs assume that HHs do not experience limitations in terms of labour and/or capital whereby the marginal income of e.g. crop farming are valid and constant for all hectares on a given farm. This, however, is often not the case. Some HHs (e.g. small families on large farms) can only maintain a certain marginal income from farm land up to a maximum area determined by either labour or capital constraints; beyond this maximum area, the marginal income is de facto zero. It would clearly be advantageous to develop the HIM further to incorporate these aspects so that PES-program participation, private information rent and additionality can be a priori estimated based on key HH input data and parameters. Such a model will be presented in a forthcoming paper.

5 CONCLUSIONS

While the HIM has weaknesses and needs further validation, it does show a certain robustness and it possesses desirable features in linking measurable real life phenomena with an explanatory model, enabling verification of model predictions. Also, it requires a modest amount of upfront data collection for robust prediction of PES impacts. The income model illustrates the importance of considering HH constraints as well as changes in POCs as a consequence of conditions beyond the influence of the HH. It illustrates that unconstrained opportunity costs as commonly presented are an inadequate measure of the foregone HH income, which is what PES is meant to match as a point of departure. In the concrete case, the relatively large farms illustrate how PES efficiency drops because there is no immediate threat to forests on farms: HHs frequently do simply not have enough manpower to cultivate their entire farm, nor do they have available capital to hire additional farm labour. Low productivity is in El Castillo also a factor, making paid off-farm work an attractive option, likewise meaning a higher opportunity cost of staying at one's own farm if yields are low.

The case study illustrates a number of intra-household and contextual factors, which modify PES impact, first and foremost available family farm labour, land and forest assets, as well as labour market conditions and access to capital. It also demonstrates that these conditions are related in more complex ways than a 'simple' flat-rate OC can account for, and the trade-off within HH and on-farm are not well predicted based on this. Calculating detailed opportunity costs for HHs in the case study, reveals large variations in POCs among superficially similar HHs as well as large spatial on-farm variations, indicating a large scope for misjudging willingness to participate in PES if only an average POC is applied. In parallel, the magnitude of information rent of a given PES-program can a priori be estimated as the sum of the differences over the number of HHs between a flat rate PES-payment and the expected individual POCs.

While detailed calculation of POC for all individual HHs in a PES target area is naturally impractical, we nevertheless conclude that investigating POC for a representative sample population in depth may yield information enabling better price targeting and improve predictions of additionality as well as PES impacts on welfare and land use.

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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	usd/ha	PES payment
P_f	usd/tree	Selling price of wood
p_c	usd/kg	Selling price of crops (average of 5 key crops)
p_l	usd/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	usd/ha	Unit cost of converting forest/fallow into crop land
i_l	usd/ha	Unit cost of converting forest/fallow into livestock land
f_o	%	Off-farm labour market access frequency
w	usd/year	Off-farm labour wage
f_n	%	Non-farm labour market access frequency
w_n	usd/year	Non-farm labour wage
C	usd/year	Cash capital
X_t	usd/year	Total HH income
X_e	usd/year	HH income from non-farm work
X_o	usd/year	HH income from off-farm work
X_a	usd/year	HH net income from farm production
X_p	usd/year	HH net income from PES

ANNEX B: Agricultural household income model – formulation and parameter estimation

B.1 Model formulation

The specific household income model is used as a framework to estimate household POCs and subsequently to analyse the behaviour of agricultural households that might join a PES scheme, or already have. The household income model is based on a combination of a producer and a consumer into one single model, that is, the consumer is also an entrepreneur (e.g. Singh et al., 1986). In general, the household has preferences on e.g. an agricultural product, Z_a, a purchased good, Z_m, and leisure, Z_l, defined by the utility function $U(Z_a, Z_m, Z_l)$. In our concrete context we view the leisure choice variable as allocation of household time for all non-income generating purposes (school, organisations, etc.). For a production cycle of one year, the farm household is assumed to generate a net income from agricultural production and from off-farm and/or non-farm labour. The household has a production capacity represented by the production function $Q(A, L)$, where A is land area and L is labour. Total farm area, A_{tot}, is assumed fixed; however, the land-use distribution within the farm can change dependent on economic and household conditions. The income function for the household is:

$$p_m Z_m = X_C = p_a\left(Q(A, L_a) - Z_a\right) + w\left(L_f - L_a\right) \qquad \text{(B1)}$$

where w is the average wage rate for farm work and p_a is the market price of the agricultural good. The left hand side is the potential expenditure on purchased goods, which is equal to the net household income X_c. This income is generated by sale of agricultural products plus the net sale of labour on the labour market. If the amount of labour required to produce the agricultural good (L_a) exceeds the total family farm labour (L_f), the household will have to hire external labour to uphold production, or scale down production. If ($L_f – L_a$) is positive, there is a potential supply for off-farm labour.

The household income model assumes perfect markets for agricultural products, that is, the farmers can sell their surplus production at fixed prices. In addition to the budget constraint (eq. B1), the household must also satisfy the time/labour constraint:

$$X_l + L_F = L_T \qquad \text{(B2)}$$

where L_t is total stock of adult household time. Utility maximization can then be written as:

$$\max_{X_a, X_m, X_l, L_a} U(X_a, X_m, X_l)$$

subject to the so-called full income-budget constraint:

$$p_m Z_m + p_a Z_a + wX_l = wL_f + p_a Q(A, L_a) - wL_a \quad \text{(B3)}$$

In this basic formulation, various simplifications have been made. Other variable inputs to the agricultural production, such as fertilizers, pesticides and fodder, have been omitted. This is realistic in the present case study in El Castillo, where farmers generally do not have the means to purchase agricultural input. In addition, it is assumed that production is riskless and that prices (p_a and w) are not affected by household decisions. Consequently, the household is assumed to be a price-taker in the primary markets and this will result in a recursive model. This means that to maximize utility, the household must first maximize full income, which in turn implies maximizing profit, or household net income. For the present purpose, it suffices to analyse, and maximize, the household full income function:

$$X = p_a Q(A, L_a) + w(L_f - L_a) \quad \text{(B4)}$$

In the present application, we will expand the above basic model to include four different income generating land-uses (plus the necessary fallow area to enable rotation and/or fodder production), income from PES and the possibility that surplus household labour may not be able to find paid full-time off-farm work. Thus, the new net income function becomes:

$$X = p_p Q_p(A_p) + p_f Q_f(A_f) + p_c Q_c(A_c, L_c) + p_l Q_l(A_l, L_l) + f_o wL_O - wL_h + X_e(L_e) \quad \text{(B5)}$$

where the p's are unit market prices, Q's are production functions, f_o ($0 < f_o < 1$) is the proportion of farm labour surplus taking full-time off-farm employment at wage rate w, and X_e is exogenous income from non-farm work generated by L_e persons. Assuming that leisure time is minimal, the labour constraint now reads:

$$L_c + L_l + L_o = L_t - L_e = L_f \quad \text{(B6)}$$

Hence, the total time available for on-farm (crop, L_c, and livestock, L_l, production) and off-farm work, L_o, is equal to the total time available less the time that is used to generate non-farm income (skilled work, trade), which is generally significantly better paid than farm work. L_h is the hired labour, which is equal to the labour deficit according to the following conditional statement:

$$\begin{aligned} &if\ L_t - L_e > L_c + L_l\ \ then\ \ L_o = f_o\left(L_f - (L_c + L_l)\right)\ \ and\ \ L_h = 0 \\ &\qquad otherwise\ \ L_o = 0\ \ and\ \ L_h = (L_c + L_l) - L_f \end{aligned} \quad \text{(B7)}$$

In eq. B5, we have also introduced the four types of income generating land-use:

1. A_p = area enrolled under the PES-program
2. A_f = forest area in addition to the PES-area
3. A_c = the area used for annual crop production
4. A_l = the area used for livestock production

In addition, farmers may not utilize the total farm area leaving some as fallow land, A_r. The five land-uses sum up to the total land area owned by the household:

$$A_p + A_f + A_c + A_l + A_r = A_{tot} \tag{B8}$$

The second land constraint that must be satisfied is that the PES-area and remaining forest area must add up to the original forest area (A_{of}), i.e. the total forest area prior to enrolling A_p in a PES scheme:

$$A_p + A_f = A_{of} \tag{B9}$$

Assuming that use of labour in PES and forest areas is insignificant compared to labour input to agricultural production, the production functions are now given as:

$$Q_p = A_p \tag{B10}$$

$$Q_f = y_f A_f$$

$$Q_c = y_c A_c$$

$$Q_l = D_l y_l A_l$$

$$Q_r = y_r A_r = 0$$

Linear production functions are chosen in order to keep the number of model parameters at a minimum. At the same time, this formulation has generated interview questions that are easily understood by farmers, and it allows explicit estimation of parameters based on the interview responses, i.e. the link between model parameter and empirically measurable item is straight forward. The production coefficients, y_i, are area-specific unit yields (yield per hectare) and D_l is the cattle density (cattle/ha). The total labour input required to sustain the crop and livestock production is calculated as follows:

$$L_c = \frac{1}{e_c} A_c \quad \text{and} \quad L_l = \frac{D_c}{e_l} A_l \tag{B11}$$

where e_c (ha/person) and el (heads of cattle/person) is effectiveness for crop and livestock production, respectively, i.e. how many hectares/heads of cattle one person can manage. Inserting eq. B6-B11 into eq. B5 and deducting income from exogenous non-farm work, we obtain the household farm net income function with six choice variables (A_r does not generate income), where r_s is the share of the total agricultural production that is sold on the market:

$$X_a = p_p A_p + p_f y_f A_f + r_s p_c y_c A_c + r_s p_l D_l y_c A_l + f_o w L_o - w L_h \tag{B12}$$

From the information given by the respondents, it is not possible to determine how much of the wood production is sold and how much is kept for own use. Respondents have reported income from sale of wood only and r_s for wood is therefore set to 1. With reference to eq. B1, own consumption, Z_a, therefore is equal to (1 - r_s)(Q_c + Q_l). In this version of the net income function, we have assumed that (1-f_o)L_o persons are available for own farm production without extra costs. When own labour resources are fully utilised, the required hired labour will enter the crop and livestock production functions as costs according to the respective efficiencies, i.e. w/e_c and wD_l/e_l. The maximization problem given an actual land-use distribution can then be written as:

$$\max_{A_p, A_f, A_c, A_l, A_r} Y(A_p, A_f, A_c, A_l, A_r, L_O, L_H) \quad \text{(B13)}$$

subject to the constraints:

1. $A_p + A_f + A_c + A_l + A_r = A_{tot}$
2. $A_p + A_f \leq A_{of}$
3. $A_c + A_l \geq A_s$
4. $L_c + L_l + L_o - L_h = L_t - L_e = \frac{1}{e_c} A_c + \frac{D_l}{e_l} A_l + L_o - L_h$
5. $i_c(A_c - A_c^0) + i_l(A_l - A_l^0) \leq C \;\Rightarrow\; i_c A_c + i_l A_l \leq K + i_c A_c^0 + i_l A_l^0$

Constraint no 3 has been introduced to ensure that the household agricultural subsistence area, A_s, as a minimum is maintained for auto-consumption of agricultural products. Constraint no 2 specifies that A_p must be less than the original forest area, however, allowing that part or all of A_f can be converted into agricultural use. The opposite option, that A_c or A_l be converted into forest, is not a valid choice. Constraint no 4 specifies that the total household labour time after subtracting non-farm work must be divided between farm work, off-farm work and hired labour. Here we assume that leisure time is minimal compared to the time required to ensure subsistence of the household. Constraint no 5 expresses that expansion of the agricultural production area is conditioned on the availability of capital needed to convert e.g. forest to cropland or the investment in cattle to establish a livestock herd. Here i_c and i_l are unit initial investment requirements (usd/ha) and A_c^0 and A_l^0 are present crop and livestock areas, respectively. By definition, the land constraint (no 1) is always binding. The same is true for the full labour constraint (no. 4), whereas constraints 2, 3 and 5 may or may not be binding, and the household net income maximization problem will generally have to be solved numerically using linear programming technique.

B.2 Direct estimation of model parameters from collected HH data

The household model requires a set of input data, which are considered constant and where values are based on information given by the respondents. In addition to the input data, the model contains six key parameters which are estimated for each household based on the information given by respondents:

1. Crop production yield, y_c (kg/ha/year);
2. Livestock density, D_l (heads/ha);
3. Livestock production yield, y_l (heads/year);
4. Share of agricultural production that is sold, r_s (%);
5. Crop production efficiency, e_c (ha/person); and
6. Livestock production efficiency, e_l (heads/person)

Estimates of the probability of available farm labour supply getting off-farm full-time occupation, f_o (%), can be obtained only from those participants that have actually had household members taking paid off-farm work.

Estimators of the six model parameters can be found recursively from the participants' data on crop and livestock production, income from farm production (excluding PES), income from off-farm and non-farm work and payments to external labour. The estimator of crop yield production, y_c, is:

$$\hat{y}_c = \frac{Q_c^{obs}}{A_c} \tag{B14}$$

The estimator of cattle density is for $A_l > 0$ (and 0 otherwise):

$$\hat{D}_c = \frac{N_c^{obs}}{A_l} \tag{B15}$$

Livestock production yield, y_l, and the share of agricultural production that is sold, r_s, are estimated by iteration using the farm income sub-model:

$$\min\left(Y_a^{obs} - \hat{r}_s\left(p_c Q_c^{obs} + p_l \hat{y}_l \hat{D}_c A_l\right)\right) \tag{B16}$$

Y_a^{obs} (usd/year) is participants' information on cash income from farm production and $\hat{r}_s\left(p_c Q_c^{obs} + p_l \hat{y}_l \hat{D}_c A_l\right)$ is the simulated value of total production (= sale and household consumption). The estimator of crop production efficiency, e_c, is:

$$\hat{e}_c = \frac{A_c^{obs}}{L_c^{obs}} \tag{B17}$$

where L_c^{obs} is the reported amount of time spent on crop cultivation. Similarly, the livestock production efficiency, e_l, is estimated as:

$$\hat{e}_l = \frac{A_l^{obs}}{L_l^{obs}} \tag{B18}$$

Finally, the estimator of f_o is:

$$\hat{f}_o = \frac{L_o^{obs}}{L_F - L_a} \qquad \text{(B19)}$$

For households where all available labour is used for agricultural production, f_o is 0. This parameter is somewhat ambiguous in so far as it measures either the amount of leisure time ($L_s = L_f - L_a - L_o$) or the access to off-farm labour. In the first case, the household has preferences for spending time on something else than farm production. In the latter case, there may not be a market for selling household surplus labour. Some participants have reported that taking paid off-farm work, if possible at all, is generally preferred to working on own farm because (1) off-farm work can give a stable income and (2) the possibility of cash income from own products is relatively low and only a realistic option for effective farmers on farms with enough land of sufficient soil fertility. In view of this we primarily see f_o as a measure of how open the off-farm labour market is.

ANNEX C: Key observed household data – comparison of group averages

Description	Variable	Unit	PES-group Mean of Obs	CON-group Mean of Obs	Difference D	P(D<>0)
Total farm area	A_{tot}	ha	87.7	32.6	55.1	83.4%
Original forest area	A_{of}	ha	61.2	15.8	45.3	81.1%
PES area	A_p	ha	20.9	0.0	0.0	N/A
Forest area	A_f	ha	40.3	15.8	24.4	54.3%
Crop area	A_c	ha	4.0	2.6	1.4	76.8%
Livestock area	A_l	ha	11.3	6.9	4.4	58.7%
Fallow/rotation area	A_r	ha	11.3	7.2	4.1	66.8%
Household size	N_h	persons	6.5	5.0	1.5	86.6%
Non-farm labour	L_e	persons	0.4	0.3	0.2	43.5%
Labour available for farming	L_f	persons	3.2	2.4	0.9	87.3%
Own-farm labour	L_a	persons	2.9	1.7	1.1	*97.6%
Hired labour	L_h	persons	0.1	0.1	0.1	79.6%
Off-farm labour	L_o	persons	0.2	0.5	-0.3	88.3%
Total HH income	X_t	usd/year	2247	1657	590.1	74.4%
Non-farm income	X_e	usd/year	956	632	324.0	43.5%
Off-farm income	X_o	usd/year	120	339	-219.4	88.3%
PES income	X_p	usd/year	628	0	0.0	N/A
Net income from farm production	X_a	usd/year	447	646	-199.1	60.7%
Cost of hired labour	C_h	usd/year	97	40	57.0	79.6%
Relative net HH income	X_t/N_h	usd/cap/year	1.0	1.0	0.0	5.0%
Education level	*edu*	%	3.0	2.8	0.2	15.9%
Crop production	y_c	kg/ha/year	654	758	-103.9	79.5%
Crop effectiveness	e_c	ha/cap	1.5	1.7	-0.2	54.4%
Livestock density	D_l	heads/ha	1.2	1.3	-0.1	20.2%
Livestock effectiveness	e_l	heads/cap	40	46	-6.3	43.9%
Livestock production	y_l	%	19	24	-5.0	65.5%
Share of farm production that is sold	r_s	%	30	34	-4.0	31.5%

* Significant on 95% level

ANNEX D: CON-group simulation results (c8 and c9 omitted because they have forest area less than the minimum target)

HH	A_p (ha)	A_f (ha)	A_c (ha)	A_l (ha)	A_r (ha)	L_o (cap)	L_h (cap)	X_0 (usd)	ΔX^* (usd)	$\Delta X^*/X_0$ (%)
c6	28.2	-28.2	-0.5	0.3	0.1	0.5	0.0	280	883	315%
c14	21.1	-21.1	0.0	0.0	0.0	0.0	0.0	302	332	110%
c7	8.5	-8.5	0.0	0.0	0.0	0.2	0.2	885	445	50%
c1	28.2	-28.2	0.0	0.0	0.0	0.0	0.1	1,178	1,018	86%
c18	10.6	-10.6	0.0	0.0	0.0	0.5	0.0	1,187	190	16%
c13	8.5	-8.5	0.5	-0.4	-0.2	0.0	0.0	1,253	327	26%
c4	24.6	-24.6	0.0	0.0	0.0	0.5	0.1	1,630	761	47%
c5	14.1	-14.1	-1.9	1.3	0.6	1.1	0.0	1,654	691	42%
c3	14.1	-14.1	0.1	-0.1	0.0	0.0	0.1	1,680	74	4%
c12	7.0	-7.0	0.0	0.0	0.0	0.3	0.0	1,818	194	11%
c11	12.7	-12.7	-1.2	0.8	0.4	0.3	0.0	1,832	579	32%
c15	14.1	-14.1	0.0	0.0	0.0	0.6	-0.2	1,833	13	1%
c10	21.1	-21.1	-6.6	1.8	4.8	1.5	0.0	2,093	1,626	78%
c19	21.1	-21.1	0.0	0.0	0.0	1.0	0.0	2,153	581	27%
c20	12.7	-12.7	-1.6	-3.8	5.4	1.6	0.0	2,450	864	35%
c16	28.2	-28.2	0.0	0.0	0.0	0.3	-0.4	2,506	492	20%
c2	5.6	-5.6	0.0	0.0	0.0	0.3	0.0	3,134	149	5%
c17	18.3	-18.3	0.0	0.0	0.0	0.1	0.0	4,006	264	7%
Sum	**299**	**-299**	**-11**	**0.0**	**11.0**	8.8	**0.0**	**31,872**	**9,482**	
Average	**14.9**	**-14.9**	**-0.61**	**0.00**	**0.61**	0.5	**0.0**	**1,771**	**527**	**30%**

Table D.1: Results of scenario simulation: S1 – S0. S0 is actual situation and S1 is after PES being offered as an opportunity. No cash input and off-farm labour frequency as found from case study interviews. HHs are sorted according to pre-PES total income, X_0, and the four HHs that are expected to benefit relatively most are marked.

HH	A_p (ha)	A_f (ha)	A_c (ha)	A_l (ha)	A_r (ha)	L_o (cap)	L_h (cap)	X_1 (usd)	ΔX^* (usd)	$\Delta X^*/X_1$ (%)
c14	0.0	0.0	-0.1	3.5	-3.4	0.0	0.0	634	602	95%
c6	0.0	0.0	-2.4	6.0	-3.7	1.2	0.0	1,163	747	64%
c7	0.0	0.0	0.5	0.0	-0.5	-0.2	0.0	1,330	154	12%
c18	0.0	0.0	0.8	1.2	-2.0	-0.5	0.0	1,377	217	16%
c13	0.0	0.0	-0.2	1.5	-1.3	0.0	0.0	1,580	26	2%
c3	0.0	0.0	0.0	0.3	-0.3	0.0	0.0	1,754	6	0%
c15	0.0	0.0	1.4	0.0	-1.4	-0.6	0.0	1,846	568	31%
c12	0.0	0.0	0.0	1.1	-1.1	0.0	0.0	2,011	0	0%
c1	0.0	0.0	-0.1	4.7	-4.6	0.0	0.0	2,196	15	1%
c5	0.0	0.0	0.0	2.3	-2.3	0.0	0.0	2,345	57	2%
c4	0.0	0.0	0.8	3.5	-4.3	-0.5	0.0	2,391	338	14%
c11	0.0	0.0	-1.4	1.8	-0.4	0.6	0.0	2,411	595	25%
c19	0.0	0.0	1.4	2.5	-3.9	-1.0	0.0	2,734	250	9%
c16	0.0	0.0	-1.1	5.4	-4.3	0.6	0.0	2,998	257	9%
c2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,283	0	0%
c20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,314	0	0%
c10	0.0	0.0	0.0	6.3	-6.3	-0.1	0.0	3,719	178	5%
c17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4,269	0	0%
Sum	**0.0**	**0.0**	**-0.4**	**40.1**	**-39.7**	**-0.6**	**0.0**	**41,354**	**4,010**	
Average	**0.0**	**0.0**	**0.0**	**2.2**	**-2.2**	**0.0**	**0.0**	**2,297**	**223**	**10%**

Table D.2: Results of scenario simulation: S2 – S1. S1 is after PES being offered as an opportunity and S2 is with PES and full cash input. Off-farm labour frequency as found from case study interviews. HHs are sorted according to total income, X_1, obtained after introduction of PES.

HH	A_p (ha)	A_f (ha)	A_c (ha)	A_l (ha)	A_r (ha)	L_o (cap)	L_h (cap)	X_1 (usd)	ΔX^* (usd)	$\Delta X^*/X_1$ (%)
c14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,235	0	0%
c7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,484	0	0%
c18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,595	0	0%
c13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,606	0	0%
c3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,760	0	0%
c6	0.0	0.0	3.6	-3.6	0.0	-1.9	0.0	1,910	-90	-5%
c12	0.0	0.0	1.6	-1.1	-0.5	-1.1	0.0	2,011	-660	-33%
c1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,211	0	0%
c5	0.0	0.0	2.8	-2.0	-0.8	-1.6	0.0	2,402	-224	-9%
c15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,413	0	0%
c4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,729	0	0%
c19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,983	0	0
c11	-1.9	0.0	4.9	-2.7	-0.3	-2.2	0.0	3,005	-673	-22%
c16	0.0	0.0	2.5	-1.8	-0.8	-2.2	-0.4	3,255	-370	-11%
c2	0.0	0.0	2.6	-2.5	-0.1	-2.6	0.0	3,283	-952	-29%
c20	0.0	0.0	2.5	-2.5	0.0	-2.4	0.0	3,314	-1,005	-30%
c10	0.0	0.0	7.2	-5.2	-2.0	-1.9	0.0	3,897	-220	-6%
c17	0.0	0.0	1.6	1.9	-3.5	-1.1	0.0	4,269	-480	-11%
Sum	**-1.9**	**0.0**	**29.3**	**-19.4**	**-8.0**	**-17.0**	**-0.4**	**45,364**	**-4,674**	
Average	**-0.1**	**0.0**	**1.6**	**-1.1**	**-0.4**	**-0.9**	**0.0**	**2,520**	**-260**	**-10%**

Table D.3: Results of scenario simulation: S3 – S2. S2 is after PES being offered as an opportunity and with full cash input. S3 is equal to S2 but with off-farm labour frequency reduced to zero. HHs are sorted according to total income, X_2, obtained after introduction of PES and full PES-payment available as cash input.