Cost efficiency of smallholder payment for ecosystem services (PES) scheme in rural Kenya

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Abstract

Smallholder farmers in sub-Saharan Africa that sequestrate carbon through agroforestry provide ecosystem services that generate payment for ecosystem services (PES). When these farmers are inadequately compensated for the provision of additional ecosystem services they have no incentive to participate while over-compensation may lead to inefficient schemes. Stakeholders must consider farm-level interactions between agricultural production and ecosystem services' provision when evaluating the adequate level of compensation and efficiency of PES scheme. We address this by measuring the marginal cost of ecosystem services based on farm level bio-economic interactions. A classification of the relationship between marketed agricultural output and *non-marketed ecosystem services* into complementary, supplementary or competitive is conducted. We use the flexible transformation function for our theoretical analysis and surveyed 120 smallholder farmers receiving PES for agroforestry carbon sequestration in Kenya. The results suggest that the joint production for a number of smallholder farms in Kenya may not be of a complementary nature. PES schemes could be designed in a more efficient manner if they would target smallholder farms based on the aforementioned classification by offering a range of contracts to encourage competitive bidding.

Key Words: Cost-efficiency, payment for ecosystem services, agroforestry, smallholders, Kenya, Sub-Saharan Africa

INTRODUCTION

Agroforestry provides ecosystem services, contribute to food production, soil improvement, erosion control, biodiversity and carbon sequestration. Furthermore, there are certain medicinal and

spiritual aspects associated with agroforestry ecosystem services in many parts of sub-Saharan. Agroforestry ecosystem services on farmlands are therefore beneficial to society and improve human livelihood. Although the primary goal of agriculture is food production, there are a number of ecosystem services such as pest control etc. that agriculture provides to agroforestry that enhances its performance and resilience. Agriculture in itself also requires several agroforestry ecosystem services as crucial inputs for its production. For instance, soil fertility enhancement from agroforestry may act as a substitute for fertilizer (reduce fertilizer use) in agricultural systems. Agricultural ecosystem services are a source for inputs and can also provide complementary outputs in the production system. Therefore ecosystem services provided by agroforestry and agriculture are interrelated.

A simple marginal cost analysis for the agroforestry ecosystem services generated which neglects the production relationship to agricultural output based on a joint farm-level output structure may be bias and not robust. Such a relationship can influence farmers opportunity cost, directly impacting the design of a cost-effective PES program (Sauer and Wossink, 2013). This may have far-reaching consequences with respect to an efficient policy design for sub-Saharan African countries. The method proposed in this study allows for a complementary, supplementary and competitive relationship in the joint output structure at the farm level and hence contributes to existing literature on PES in developing countries. A flexible Generalized-Leontief transformation function that estimates multi-input-output production relationships is applied. Farmers are not only classified with respect to the prevailing production relationship but also their respective opportunity costs.

The remainder of the paper is as follows: Section 2 outlines the conceptual framework which serves as basis for the empirical analysis developed in section 3. This is followed by the description of the data in section 4. Subsequently, the results and empirical analysis are discussed in section 5 whereas section 6 concludes the study by highlighting implications of the analysis with respect to a more efficient PES policy design.

CONCEPTUAL FRAMEWORK

Agroforestry soil fertilization improvement can be considered a non-marketed ecosystem service for agriculture because it is produced alongside agricultural output and contributes to agricultural productivity. Although not all agroforestry related services improve soil fertilization or provide a limited erosion control, we assume that farmers choose from a range of trees that improve the quality of their fields and livelihoods.

PES schemes for smallholder farmers usually prescribe certain measures which farmers have to fulfill before they can be admitted into such programs. Examples of such measures include the minimum number of trees required to be cultivated on given farmland, farming practices that limits tillage, use of

mulching as well as mandatory attendance of meetings for individual farmers. This minimum standard in PES schemes is denoted as Z_0, while the ecosystem services constraints given the limited resources such as farmland (input) available to farmers is denoted as Z_1.

The product-product relationship for a production process with multiple outputs can be described to be competitive, complementary, or supplementary in nature. In a competitive relationship, an increase in agricultural products and ecosystem services production cannot be simultaneously observed. This implies that one product has to be decreased for another to increase. Conversely, in a complementary relationship, the production of agricultural products and ecosystem services can simultaneously increase up until a point- (*so-called* A). This implies that increasing ecosystem services contribute to an increase in agriculture production. The supplementary relationship also indicates that the production of agricultural products and ecosystem services could be simultaneously increased up until point A, although to a much lesser degree when compared to the complementary relationship. Supplementary relationship represents a combination of a complementary and competitive situation. The joint production relationships can be termed a compatible product-product relationship. It is however important to note that there are some ecosystem services provided at the farm level which are inseparable.

The shadow price associated with the different relationships above is linked to the opportunity cost of providing marginal ecosystem services which also reveals the cost-effectiveness of the PES schemes. Participation in PES schemes is feasible when marginal ecosystem services result in opportunity cost of zero (complementary and supplementary scenarios). Smallholders that are not adequately compensated for forgone income of providing marginal ecosystem services given the constraint Z_1, accrue higher cost compared to those who are overpaid and doesn't experience additional cost for the provision of marginal ecosystem services.

For the classification of farms into the relationships discussed above, it is important to know the level of ecosystem services contribution and determine the shape or curvature of the production possible frontier - PPF to ascertain that the possibility of a relationship which is potentially of a non-concave (convex) nature is not given. This shape or curvature is influenced by individual farm characteristics and socioeconomic factors such as farm size, age, farm revenue etc.

EMPIRICAL FRAMEWORK

For the empirical analysis we rely on a transformation function incorporating multiple outputs and inputs. A transformation function represents the output producible from a given input base and existing conditions, which also represents the feasible production set. The transformation function in general form can be written as $0 = G(\mathbf{Y}, \mathbf{X}, \mathbf{T})$, where $\mathbf{Y}$ is a vector of outputs, $\mathbf{X}$ is a vector of inputs and $\mathbf{T}$ is a vector of variables

representing the exogenous production environment. The transformation function $0 = G(\mathbf{Y},\mathbf{X},\mathbf{T})$ reflects the maximum amount of outputs generated from a given input vector and external conditions.

Based on the implicit function theorem, if $G(\mathbf{Y},\mathbf{X},\mathbf{T})$ is continuously differentiable and has non-zero first derivatives with respect to one of its arguments, it may be specified (in explicit form) with the argument on the left hand side of the equation. Accordingly, we estimate the transformation function $Y_1 = H(\mathbf{Y_{-1}},\mathbf{X},\mathbf{T})$, where, Y_1 is the agricultural output of the farms and Y_{-1} represents ecosystem services related payments to represent the technological relationships for the farms in our data sample. Note that this specification does not reflect any endogeneity of output and input choices, but simply represents the technological maximum of Y_1 that can be produced given the levels of the other arguments of the $H(\cdot)$ function (see also Felthoven and Morrison-Paul 2004 and Sauer and Wossink 2013).

To statistically estimate this transformation function we apply a flexible functional form (second order approximation) to accommodate various interactions among the arguments of the general function. The generalised linear functional form suggested by Diewert (1973) to avoid problems with mathematical transformations of the original data (e.g. taking logs of variables which would lead to modelling problems with zero values) was used:

$$Y_A = H(Z_{ES}, X, T)$$

$$= \alpha + 2\alpha_{ESES}Z_{ES}^{0.5} + \sum_{k=1}^{K} 2\alpha_{kk}X_k^{0.5} + \beta_{ES}Z_{ES} + \sum_{k=1}^{K} \beta_k X_k + \sum_{k=1}^{K}\sum_{l=1}^{K} \gamma_{kl}X_k^{0.5} X_l^{0.5}$$

$$+ \sum_{k=1}^{K} \gamma_{kES}X_k^{0.5} Z_{ES}^{0.5} + \sum_{m=1}^{M} \tau_m T_m + v$$

[1]

Where Y_A is the total agricultural output (identical to Y_1 above) and Z_{ES} denotes total output under the agroforestry PES scheme as the component of Y_{-1}. X denotes inputs with land, labor, fertilizer, organic fertilizer and pesticides. The vector T is a proxy for the farm production environment and structure (e.g. age, location etc.).

To account for observed and unobserved heterogeneity with respect to a farmer's decision to join the PES program we use Heckman two stage sample selection. A farmer's decision is influenced by a multitude of factors: socioeconomic characteristics at the farm level, personal experiences based on social interaction with other farmers as well as locational characteristics. Our final estimation model is based on two latent dependent variables models, where the decision to participate or not is modelled as a selection equation specified as:

$$P_i = \begin{Bmatrix} 1 \text{ } if \text{ } \alpha + \sum_{m=1}^{M}\tau_m T_m + u > 0 \\ 0 \text{ } otherwise \end{Bmatrix}$$

[2]

Where P_i is a binary variable which takes the value one if the farmer is participating in PES and zero if the farmer decided not to participate, T denotes the vector of potentially explaining variables, τ as the parameter to be estimated, and u is the error term. The second part, the outcome equation, is given by the transformation function [1] model outlined above where the dependent variable Y_A represents the level of agricultural output produced by each farm and the parameters α, β, and γ as the parameters to be estimated and v as stochastic noise.

According to Heckman's specification, the error terms, u and v are assumed to follow a bivariate normal distribution where $v \sim N(0,1)$ and $E(u|v) = \omega v$; ω is a constant and $\omega = 0$ indicates that u and v are uncorrelated, otherwise u and v are correlated (see Heckman 1979).

For the approximation of the farms' production structure, we evaluate the first- and second-order elasticities of the transformation function. The first-order elasticities in terms of agricultural output Y_A represent the (proportional) shape of the PPF (given inputs) for output Z_{ES} and the shape of the production function (given other inputs and Z_{ES}) for input X_k – or output trade-offs and input contributions to agricultural output, respectively. This study estimates;

(a) Output elasticity with respect to "other" outputs: $\varepsilon_{AO,ES} = \partial \ln Y_A / \partial \ln Z_{ES} = \partial Y_A / \partial Y_{ES} * (Y_{ES}/Y_A)$ which is expected to be negative as these reflect the slope of the PPF, with the magnitude capturing the (proportional) marginal trade-off between agricultural - and ecosystem service output.

(b) Output elasticities with respect to inputs X_k, $\varepsilon_{Ak} = \partial \ln Y_A / \partial \ln X_k = \partial Y_A / \partial X_k * (X_k/Y_A)$ are expected to be positive, with its magnitude representing the (proportional) marginal productivities of X_k.

For further elaboration on the theoretical model above evaluated empirically in this study see Sauer and Wossink (2013).

DATA

The international small group tree planting program (henceforth TIST) is an agroforestry PES scheme with operations in four countries; Kenya, India, Tanzania, Uganda. The TIST program started operating in Kenya in 2005 in Embu, Meru, Nanyuki and Mara, and has since attracted over 60,000 farmers in their program planting ca. 7.5 million trees in over 2000 villages (TIST, 2012). Smallholder farmers, apart from earning payments for ecosystem services (PES) for each unit of carbon sequestrated with respect to a pre-determined number of surviving trees on their farmland, also receive farm management training. There is a fixed price paid for each ton of carbon dioxide equivalent (CO_2e) sequestrated from emission trading in the voluntary carbon market. This price should indicate the relative changes in the production strategy that smallholders are willing to tolerate from the perspective of the

project developers. Thus, PES may be perceived as a measure of the underlying ecosystem service product – agricultural product relationship which farmers experience on their farmland. The true value and level of ES may differ considerably and are unlikely to be adequately estimated given their ecological and structural complexity (Sauer and Wossink, 2013).

The pre-determined number of trees each TIST farmer is required to cultivate on his/her farmland to qualify for PES is between 420 and 840 trees. The fixed amount of payment that farmers earn per tree per year is US$ 0.02 for trees that are counted and are older than six months (Shames et al. 2013). However, where the TIST program reports a net profit, smallholder famers would receive higher payments per tree (Shames et al. 2013). Since the benefits and costs of ecosystem services to farmers who are members of the TIST program are not necessarily uniform, it is worthwhile to ensure that PES do not exceed or fall below any forgone income and additional cost associated with the provision of ES. The issue of the opportunity cost of allocating land to tree cultivation has also been identified by the TIST program management as one of the decision-making hurdles confronting both farmers with limited land as well as landless farmers (Shames et al. 2013).

The ecosystem services provided through agroforestry per farm (i.e. carbon sequestration from trees) is assumed a "***non-marketed output***" rewarded by a payment for ecosystem services. We use the term "***non-marketed output***" as PES originates through an emission market mechanism that is in its developmental stage and prices are not always a true representation of the fair price of carbon per ton – see Benjamin 2015. The farmers that join the TIST program have committed themselves, through contractual means, to a long term project as they cultivate and manage trees on their farmlands for a period ranging between 30-40 years. The amount of carbon captured and stored through tree carbon sequestration within the TIST project between 2009 and 2012 was estimated at ca. 209,613 tons (Shames 2013). These units of sequestrated carbon are then traded on the voluntary carbon market which results in financial means used as PES to the individual TIST farmers.

ANALYSIS AND RESULTS

The estimated transformation function - shows a reasonable statistical significance given the relatively small sample size (more than 50% of the functional arguments are significant at a 10% level of significance). The estimated Heckman selection procedure delivered no robust evidence for a bias due to the TIST participation - see table 1. Since estimated coefficients of the transformation function cannot be directly interpreted, elasticities (input and output) are therefore estimated as a combination of various parameter estimates and observed variables (the estimates first Order Elasticities at the Sample Means can be obtained from the authors upon request). It is important for a transformation function, the estimated function, to be concave in both inputs and outputs i.e. functional regularity conditions. We test for this by checking the

signs of the second derivatives with respect to all outputs and inputs (Sauer and Morrison-Paul, 2011). These indicate that marginal productivity is increasing at a decreasing rate, and the output trade-off is decreasing at an increasing rate, so second derivatives with respect to Y_{ES} and X_k are indeed negative (concavity with respect to both outputs and inputs; elasticity and concavity estimates can be obtained from the authors upon request).

The estimated parameters for the selection equation (see table 1) confirm the findings by Benjamin and Blum (2015) and other related studies conducted earlier: The probability of a farm participating in TIST increases when the neighbors are TIST members. Furthermore, older farmers and farms located in the Central and Meru region are more likely to participate in the agroforestry scheme. Finally, belonging to a cooperative positively impacts the likelihood of participating in TIST.

Table 1 Estimates Generalized-Leontief Transformation Function with Sample-Selection

Parameter	Estimate	Bootstrapped Standard Error
Selection Equation – Dependent TIST Participant (1-yes, 0-no)		
neighbor_tist	0.6166***	0.0811
age	0.0063***	0.0022
cooperative	0.1899***	0.0717
central	0.1886	0.2035
eastern	-0.1419	0.1779
kirinyaga	-0.0023	0.2096
laikipia	-0.2051	0.2423
meru	0.0724	0.2092
nyeri	-0.6731**	0.3296
constant	-0.2328	0.2269
Outcome Equation – Dependent Agricultural Income		
land	-2.4369	1.9476
labor	1.6369	1.2891
fertilizer	0.0561	0.1283
organic fertilizer	0.0121	0.0378
pesticides	-0.9562	0.7263
ecopayments	0.0917*	0.0472
land*land	3.6589*	1.9698
labor*labor	0.3744	1.0123
fertilizer*fertilizer	0.0234*	0.0152
organic fertilizer*organic fertilizer	0.0007	0.0014
pesticides*pesticides	1.3452**	0.5908
ecopayments*ecopayments	0.0018	0.0014
land*labor	-3.1195	2.4297

land*fertilizer	0.2335	0.3169
land*org fertilizer	-0.1269*	0.0719
land*pesticides	5.0174***	1.9149
labor*fertilizer	-0.2145	0.2056
labor*org fertilizer	0.1276*	0.0725
labor*pesticides	-1.2695	1.0444
fertilizer*org fertilizer	-0.0136*	0.0076
fertilizer*pesticides	0.0539*	0.1238
org fertilizer*pesticides	-0.0711*	0.0412
ecopayments*land	-0.1201*	0.0715
ecopayments*labor	0.0213	0.0566
ecopayments*fertilizer	-0.0136*	0.0076
ecopayments*org fertilizer	0.0052**	0.0023
ecopayments*pesticides	-0.1311***	0.0505
constant	-1.7098	2.1441
Mills ratio	-0.1857	0.1487
rho	-0.4787	
sigma	0.3879	
Wald chi2(9)	92.46***	

*,**,*** : significance at 10%- , 5%- , or 1%-level.

Table 2 summarizes the direct and indirect marginal productivity effects with respect to ecosystem related payments (PES) and all inputs. These total direct and indirect marginal effects are estimated from the perspective of the primary agricultural output, thus, not the same as their own second-order and cross elasticities. The mean direct effect of PES (Z_{ES}) on agricultural ouput is negative suggesting diseconomies of scope. Increasing on average ecosystem services by 1 unit (corresponding to a payment of 1 Kenyan shilling - Ksh) implies a decrease in agricultural output by Ksh 222.26. The total direct effect of a marginal change in all inputs on agricultural output has been estimated at about 17429.31 Ksh with a minimum of about 9138.825 Ksh and a maximum of about 25719.8 Ksh.

Table 2 Descriptive Statistics for Direct and Indirect Effects

Direct Effect	Mean	Std Dev[1]	Min	Max
∂YAGINC / ∂Z ECOPAY	-222.264	131.982	-483.602	39.073
∂YAGINC / ∂X LAND	1572.559	69.3056	1435.327	1709.791
∂YAGINC / ∂X LABOR	2203.706	254.055	1700.651	2706.76
∂YAGINC / ∂X FERT	4449.383	3386.834	-2256.887	11155.65
∂YAGINC / ∂X ORG FERT	1050.084	201.245	651.6	1448.568
∂YAGINC / ∂X PEST	8153.58	4559.439	-874.564	17181.72
∂YAGINC / ∂X K	17429.31	4186.903	9138.825	25719.8

Indirect Effect	Mean	St Dev	Min	Max
∂^2YAGINC / ∂Z ECOPAY ∂X LAND	129.710	63.163	4.640	254.781
∂^2YAGINC / ∂Z ECOPAY ∂X LABOR	-62.973	30.669	-123.701	-2.245
∂^2YAGINC / ∂Z ECOPAY ∂X FERT	-46.873	23.493	-93.392	-0.354
∂^2YAGINC / ∂Z ECOPAY ∂X ORG FERT	-39.089	22.815	-84.266	6.087
∂^2YAGINC / ∂Z ECOPAY ∂X PEST	-30.373	14.794	-59.667	-1.079
∂^2YAGINC / ∂Z ECOPAY ∂X K	-49.598	29.037	-107.094	7.898

[1]calculated at individual observations.

Table 2 also reports the indirect effects for all inputs and the ecosystem related output considered in the transformation model. The total indirect productivity effect of a unit change in all inputs via the ecosystem service related output Z_{ES} (∂^2YAGINC / ∂Z ECOPAY ∂X_K) varies across the sample of TIST participating farms with a mean value of about Ksh -49.598 with a minimum of Ksh -107.094 and a maximum of Ksh 7.898. The estimated indirect effect is relatively small in comparison to the direct marginal effect of total input use on agricultural output (∂YAGINC / ∂X_K) which suggests that the direct marginal effects dominate the indirect marginal effects (see table 2). The positive marginal indirect effect by the input land (Ksh 129.710) confirms the findings by earlier studies on the production relevance of scarce land for PES programs.

The direct and indirect effects are then combined as outlined in the modelling section to evaluate for each farm in the sample the nature of its product-product relationship (complementary, supplementary or competitive). The results are reported in table 3 indicating the relationship between agricultural output and ecosystem service related output. The majority of farms in the sample (79% or 95 farms) showed a supplementary relationship between the two outputs (i.e. the combined net effect is positive). About 15% (or 18 farms) of participating farms in the sample showed a complementary relationship (i.e. the direct and indirect effect are both positive), and about 5% of all farms (or 7 farms) showed a competitive relationship (i.e. the combined net effect is negative) between agricultural and ecosystem output.

Table 3 Observations Per Product-Product Relationship

Relationship considered:	Y_{AO}
	Z_{ECOPAY}
	X
Total Direct Effect	Σ_i (∂Y_{AGINC} / ∂X_i)
Total Indirect Effect	Σ_i ($\partial^2 Y_{AGINC}$ / ∂Z_{ECOPAY} ∂X_i)
Case I - complementary	18

Case II - supplementary   95
Case III - competitive   7
Total Obs.   120

Case I – direct effect and indirect effect are positive (complementary).
Case II - direct effect or indirect effect is positive, net effect is positive (supplementary).
Case III - direct effect <= 0 and indirect effect is negative (competitive).

These findings suggest that some positive level of ecosystem service provision is further possible without any reduction in the level of the other product (case II - supplementary). Furthermore, ecosystem services can be produced in increasing quantities as their provision contributes to the production of agricultural output (case I - complementary). As these results apply to the vast majority of farms in the sample (113 out of 120), this implies that current payments might not be based on the income foregone principle and exclude the private transaction costs of scheme participation. Transaction costs incurred by participants are not explicitly compensated in the TIST scheme. In this case they must be absorbed by the compensation payments available in the absence of altruism on the part of participants (see Falconer, 2000).

One of the aims of this research is to contribute to an increase in the cost-effectiveness and efficiency of agroforestry schemes in developing countries. Our estimation results indeed suggest, that such improvements might be possible (case I and II farms). With TIST scheme payments set at the national or even international level (the TIST scheme covers four countries) but implemented locally (60,000 farmers in 2000 villages in 2012), we can expect specific patterns to emerge (with respect to size, production structure, socio-economic characteristics) for the farms included in the various classes shown in table 2. Hence, in a final step, we will investigate additional farm level information in order to potentially distinguish different patterns with respect to location, geophysical conditions or socio-economic characteristics for the estimated farm categories. Table 4 summarizes various characteristics of the farms in the three estimated categories (cases I to III). We report simple descriptive statistics for locational, production and socioeconomic characteristics at farm level. As shown in table 4 farms in the three categories can be mainly distinguished along specific production patters approximated by the variables total farm income, specific cash crop related income, off-farm income, as well as individual inputs used for agricultural production (highlighted in bold).

Table 4 Characteristics Mean Values - Trade-Off Cases TIST Participants

Variable	Case I - Complementary	Case II - Supplementary	Case III - Competitive
Market distance (Km)	**2056.25**	**2657.609**	**1728.571**
Income total (Ksh)	**35679.44**	**44225.05**	**17228.57**
Off-farm income (Ksh)	**89100**	**116820**	**57000**
Eastern (Yes/No)	**0.4444**	**0.6842**	**0.7143**
Kirinyaga (Yes/No)	**0.2222**	0.0105	0
Land (Hectares)	**1.7611**	**1.0605**	**0.7286**

Labor (Workers)	**2.4444**	**2.7684**	**1**
Beans (Ksh)	7911.111	8462.632	**10285.71**
Maize (Ksh)	**13483.33**	**12083.16**	**10000**
Coffee (Ksh)	**12444.44**	**19842.11**	5000
Ecopayments (Ksh)	**1054.389**	945.4	**591.1429**
labor / land	4.705	**6.239**	3.714
ecopayments / land	1172.42	1189.177	**896.786**
income / land	**28226.58**	**79185.96**	75107.14
income / labor	**23167.87**	19148.33	15500

Case I farms show a complementary relationship between agricultural output and agroforestry related output generation i.e. that the production of both products can be further increased and that the provision of ecosystem services contributes to the production of the agricultural output. Case I farms are the largest farms in the sample using a relatively high amount of labor input. These farms produce mainly maize and coffee and generate the largest amount of ecosystem payments per farm compared to the other two classes.

Case II farms show a supplementary relationship between agricultural output and agroforestry related output generation. For these farms producing ecosystem services does not result in lower agricultural output, hence, the opportunity cost of producing more ecosystem service related output should be lower than in the last case III but higher than for case I farms.

Case III category exhibit a competitive relationship between agricultural output and ecosystem service related output which means that an increase in agroforestry output is only possible if the production of agricultural output is decreased. Farms in this category are the smallest in terms of land available for production as well as labor input used and produce mainly beans and maize.

However, without any clear patterns emerging from our rather descriptive investigation of the different farm categories, it is unlikely that identification of these farms would be straightforward. Designing a more targeted and efficient approach for TIST and similar programs could therefore result in high transaction costs. In any case, a larger panel data set would be needed to thoroughly investigate latent farm patterns with a focus on increasing the efficiency of agroforestry conservation programs.

DISCUSSION AND CONCLUSION

The biophysical relationship between the provision of environmental services and marketed agricultural output significantly influence marginal cost. Our findings suggest that a significant increase in the level of ecosystem service provision under the TIST program is further possible without any reduction in the level of the agricultural output. The majority of farms in the sample show a supplementary product-product relationship. For ca. 95% of the farms in the sample (113 out of 120), current payments by the TIST program might not reflect the true opportunity cost in these cases. However, it has

to be noted that these results do not show the production relationship within the agroforestry environmental service (e.g. soil fertility, carbon sequestration, erosion control) but rather perceives these environmental services as a bundle delivered under the TIST program.

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