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Technical Efficiency among Peasant Farmers Participating in Natural Resource Management Programmes in Central America

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Abstract

This study examines the extent to which technical efficiency (TE) is related to activities promoted by two natural resource management programmes recently completed in Central America. Data for a total of 639 farms operating in the hillsides of El Salvador and Honduras are used to estimate a household-level input-oriented stochastic distance frontier simultaneously with a TE effects model. The main finding of this study is that improvements in TE are financially beneficial to farm households while also contributing to environmental sustainability. The results also reveal a positive association between productivity and output diversification, and a positive relationship between TE and off-farm income, human capital and agricultural extension.

Keywords: *Central America; diversification economies; soil conservation; stochastic distance frontier; technical efficiency.*

JEL classifications: *D24, O13, Q01, Q12.*

1. Introduction

Central American countries face the major challenge of implementing strategies that foster agricultural development and reduce poverty while using their natural resources in a sustainable manner. Many of the various strategies adopted over the years have emphasised agricultural growth over poverty remediation and environmental

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sustainability (Johnson and Baltodano, 2004). For instance, public policies towards market liberalisation and commercial agriculture have induced large-scale farmers and cattle ranchers to acquire much of the fertile land in the valleys of Central America. Thus, small-scale farmers, who for the most part subsist on the production of two staple crops (corn and beans), have been relegated to farm on hillsides and marginal lands, relying on highly erosive production systems (Pelupessy and Ruben, 2000). As a result, there is evidence of reduced productivity among small farmers, which is in turn associated with increased rural poverty and environmental degradation (Arellanes and Lee, 2003).

To address these social and environmental problems, local governments with the support of multilateral institutions, have undertaken projects aimed at alleviating rural poverty while conserving natural resources. To reach the stated goals, these projects have attempted to improve household incomes by promoting crop diversification and soil conservation practices (Bravo-Ureta *et al.*, 2006). Two such projects, which were implemented during the past decade, are the Environmental Programme for El Salvador (PAES) and the CAJON Natural Resource Management Program in Honduras. Despite the magnitude of rural poverty and natural resource deterioration in Central America, and the efforts and financial resources that have been allocated to tackle these problems, technical efficiency (TE) studies in developing country agriculture have consistently ignored the analysis of possible links between environmental sustainability and farm efficiency (Sherlund *et al.*, 2002; Kostov and Lingard, 2004). Overlooking such interactions could have severe environmental impacts given that technical inefficiency (TI) may lead to wasteful use of natural resources, overutilisation of chemical inputs and poor soil management. On the other hand, studying the determinants of TE among small-scale farmers in less developed countries could assist policy-makers in identifying and targeting public interventions to improve farm productivity, resource conservation and household income.

Consequently, the primary goal of this study is to measure TE at the household level for beneficiaries of the PAES and CAJON projects. The main hypothesis is that by improving TE, farmers can be better-off financially while at the same time contributing to environmental sustainability. Hence, we explore the extent to which TE is related to measures promoted by the PAES and CAJON programmes. Special attention is given to examining the link between farm efficiency, soil conservation and output diversification.

The rest of the paper is organised as follows. The next section presents a review of the literature followed by a description of the analytical framework and the empirical model. Then, we discuss the empirical results and end with some concluding remarks.

2. Literature Review

As already stated, studying the potential sources of TE in rural economies is important from a practical as well as a policy point of view. Coelli and Battese (1996), and Bravo-Ureta and Pinheiro (1993) identify a number of variables that may influence TE in agriculture. Gorton and Davidova (2004) suggest that these variables should be classified into two major groups: (i) human capital and (ii) structural factors. Human capital includes variables such as formal and informal education, literacy, agricultural experience, training and farmer's age. The structural factors include family income, family size, access to credit, land tenure status, gender composition of the labour force, off-farm employment and environmental variables. A recent and comprehensive survey of TE studies in agriculture can be found in Bravo-Ureta *et al.* (2007).

The available studies analysing the impact of resource management and/or development projects on TE have focused generally on narrow issues. For instance, during the last decade, rural programmes in less favourable areas have promoted off-farm activities as a tool for development. Thus, studying the relationship between off-farm activities and farm efficiency has become quite popular in recent years. González and López (2007) conclude that off-farm income can play a key role in improving household efficiency. By contrast, O'Neill and Matthews (2000), and Ali and Flinn (1987) report a negative relationship between these two variables, suggesting that off-farm employment competes with on-farm work. The impact of credit assistance on TE has been widely studied and also produces ambiguous results. Ekanayake (1987) found a positive and significant effect of greater access to credit on TE for rice farmers in Sri Lanka. However, Deininger *et al.* (2004) conclude that the availability of credit at the local level has no impact on efficiency for farmers in Colombia. Similar results are obtained by Rios and Shively (2006), and Binam *et al.* (2003) for a sample of farmers in Vietnam and the Ivory Coast, respectively.

The impact of agricultural extension and training, education and agricultural experience on efficiency has been evaluated in several efficiency studies. An example is provided by Stefanou and Saxena (1988) who found that education and experience have significant positive effects on the level of efficiency and that in some cases these two variables can be treated as substitutes in explaining farm performance. Furthermore, O'Neill and Matthews (2000) studied the role of agricultural extension on farm efficiency in Ireland and found a positive relationship between these two variables. Kalirajan and Shand (1985) indicate that education and training have a strong and positive relationship with TE, especially among low-income farmers.

An issue that has received much less attention in the literature is the link between environmental sustainability and farm efficiency. In one of the few studies on this issue, Pascual (2005), using frontier models but with a small sample, concluded that improving TE through better input allocation and land intensification could significantly reduce soil erosion associated with slash-and-burn farming practices in Mexico. Wadud and White (2000) also report a positive association between lower levels of soil degradation and TE for a sample of rice farmers in Bangladesh.

Byiringiro and Reardon (1996), using data from a sample of small-scale farms in Rwanda, first estimated a production function and then regressed the derived marginal value productivities for land and labour on the level of implementation of soil conservation practices, among other variables. These authors found a significant positive effect of soil conservation on land productivity but they did not account for the fact that the adoption of these kinds of practices is arguably an endogenous variable. Finally, Otsuki *et al.* (2002) found that public policies related to private land ownership have reduced environmental degradation and have increased TE in the Brazilian Amazon. However, this study used a two-step procedure, a method that has been criticised by several authors arguing that it introduces serious inconsistencies in the estimation process leading to inappropriate parameter estimates for the efficiency equation in the second step (e.g. Kumbhakar *et al.*, 1991; Battese and Coelli, 1995).

The present study contains a thorough analysis of TE among 639 hillside farmers associated with the PAES and CAJON projects. Special attention is given to evaluating the impact of different measures promoted by these conservation programmes among beneficiaries. We also improve on methodological shortcomings of previous studies by implementing a single-step procedure to obtain consistent parameter estimates for the stochastic distance frontier (SDF) and the efficiency equation. Furthermore, an instrumental variables approach is used to account for the possible endogeneity of soil conservation adoption.

3. Methodological Framework

The main goal of PAES and CAJON is to improve household incomes by promoting crop diversification and soil conservation. It can be argued that these projects impact the productivity of beneficiaries from two different angles. First, promoting crop diversification may affect the shape of the production technology by directly influencing the production structure. Coelli and Fleming (2004) suggest that, in peasant economies, diversified production plans can lead to productivity gains that increase returns to land and labour. Second, controlling soil erosion can have a direct effect on TE. Thus, the farmer's level of engagement in soil conservation can affect the distance that separates observed from potential (frontier) output.

Under these circumstances, the SDF method is appropriate to study TE for two main reasons: (i) it allows for multiple outputs and inputs, which are essential for the study of farm diversification effects on productivity; and (ii) it can incorporate directly variables affecting inefficiency, which are useful in evaluating some of the measures promoted by the two conservation programmes under study. In addition, SDFs have major strengths over other multi-output techniques commonly applied in agriculture, such as the deterministic DEA method, which includes the ability to deal with stochastic noise; accommodating traditional hypothesis testing; and allowing for single-step estimation of the inefficiency effects (Kumbhakar and Lovell, 2000).

The SDF can be formulated with an input and/or an output orientation. The input orientation gives the proportional reduction in all inputs that would bring a farm to the frontier isoquant while the output model reflects the proportional increase in outputs attainable by moving to the production possibilities frontier holding input quantities constant (Alvarez *et al.*, 2005). In this paper, we choose the input orientation because it relies on a cost minimisation framework, a maintained behavioural hypothesis that is plausible for farm households in developing countries.[2] Given that producers use a vector of N inputs $(x = (x_1, \dots, x_N) \in R_+^N)$ to produce M outputs $(y = (y_1, \dots, y_M) \in R_+^M)$, the input-oriented distance function is defined as:

$$D^I(x, y) = \max\{\lambda : (x/\lambda) \in L_x(y)\} \tag{1}$$

where D^I is the input distance function, $L_x(y)$ is the set containing all input vectors x that can generate the output vector y, and λ is the efficiency score (Coelli and Perelman, 1999).

[2] Kumbhakar *et al.* (2007) present the theoretical basis to frame the input-oriented SDF within a cost minimisation model. González and López (2007) and Coelli and Fleming (2004) follow similar arguments to implement their SDF studies among peasant farmers in less favourable areas, namely, Colombia and Papua New Guinea, respectively.

From an empirical point of view, to estimate a distance function (or frontier) it is necessary to specify a functional form that adequately captures the relationship between inputs and outputs. Coelli and Perelman (1999) indicate that a second-degree approximation to a true input distance function can be represented by the following translog equations with symmetry and homogeneity imposed:

$$\ln\left(\frac{D_i^I}{x_{1i}}\right) = \alpha_0 + \sum_{m}^{M} \alpha_m \ln y_{mi} + 0.5 \sum_{m_j}^{M} \sum_{m_g}^{M} \beta_m \ln y_{m_j i} \ln y_{m_g i} + \sum_{n}^{N-1} \beta_n \ln\left(\frac{x_{ni}}{x_{1i}}\right) + 0.5 \sum_{n_j}^{N-1} \sum_{n_g}^{N-1} \beta_n \ln\left(\frac{x_{n_j i}}{x_{1i}}\right) \ln\left(\frac{x_{n_g i}}{x_{1i}}\right) + \sum_{n}^{N-1} \sum_{m}^{M} \delta_{nm} \ln \frac{x_{ni}}{x_{1i}} \ln y_{mi} + \sum_{s}^{S} \omega_s d_s \quad (2)$$

where i is a subindex for households and d_s represents all dummy variables included in the model.

Following the same rationale of the stochastic production frontier method proposed by Aigner *et al.* (1977), we can formulate an input stochastic distance frontier (ISDF), in which the distance from each observation to the ISDF represents the sum of inefficiency and a traditional error term (i.e. $\ln D^I = \epsilon = \mathrm{v} - u$). The translog-normalised ISDF can then be expressed as:

$$-\ln x_{1i} = \alpha_0 + \sum_{m}^{M} \alpha_m \ln y_{mi} + 0.5 \sum_{m_j}^{M} \sum_{m_g}^{M} \beta_m \ln y_{m_j i} \ln y_{m_g i} + \sum_{n}^{N-1} \beta_n \ln\left(\frac{x_{ni}}{x_1 i}\right) + 0.5 \sum_{n_j}^{N-1} \sum_{n_g}^{N-1} \beta_n \ln\left(\frac{x_{n_j i}}{x_{1i}}\right) \ln\left(\frac{x_{n_g i}}{x_{1i}}\right) + \sum_{n}^{N-1} \sum_{m}^{M} \delta_{nm} \ln \frac{x_{ni}}{x_{1i}} \ln y_{mi} + \sum_{s}^{S} \omega_s d_s + v_i - u_i \quad (3)$$

where u_i and v_i are the elements of the composed error term, ϵ_i, defined by Aigner *et al.* (1977). Specifically, v_i is a random variable reflecting noise and other stochastic shocks, and u_i captures TE relative to the stochastic frontier. The maximum-likelihood (ML) estimation of equation (3) will produce consistent parameter estimates for the ISDF.

Within this framework, the predictor of TE can be obtained as the expectation of the term u_i conditional on the composed error term ϵ_i (Jondrow *et al.*, 1982). Therefore, TE can be measured as:

$$\mathrm{TE} = \exp(-u_i) \quad (4)$$

Nishimizu and Page (1982), among other authors, argue that TE can be interpreted as a relative measure of managerial ability. Based on this notion, Battese and Coelli (1995) developed a single-step ML model to evaluate the extent to which TE or, more precisely, TI is a function of farm (firm) characteristics among other variables. By using this approach, the parameters of the ISDF as well as those of the TI factors are estimated jointly. This step is accomplished by incorporating the following expression into the model:

$$\mu_i = \rho_0 + \sum_{n} \rho_n F_{ni} + e_i \quad (5)$$

where μ_i is the conditional mean of u_i defined as normal random variables truncated at zero, F_{ni} is a vector of household-specific variables, ρ_o and ρ_n are unknown parameters, and e are unobservable random variables, assumed to be independently distributed. A detailed derivation of this inefficiency model can be found in Battese and Coelli (1995).

Among the F variables included in equation (5) is the level of adoption of soil conservation practices, as this variable can clearly affect TI.[3] However, previous research suggests that soil conservation adoption is a choice variable and thus might be correlated with the error term in equation (5) (Jones, 2002; Langpap, 2004). Therefore, an instrumental variable (IV) approach, similar to the one implemented by Rios and Shively (2006), is used here to account for this potential endogeneity problem.

4. Empirical Model and Data

Chavas *et al.* (2005) derive an empirical microeconomic model to study agricultural productivity in developing economies grounded on the household production paradigm. These authors argue that small-scale agriculture in less developed areas faces a variety of constraints most notably labour market rigidities and technological jointness between farm and non-farm activities. Under these circumstances, the appropriate level of analysis is the household – rather than the farm – as it allows for a more appropriate examination of production and labour decisions. Furthermore, by conducting the analysis at the household level it is possible to capture the impact of off-farm activities on agricultural productivity. This last issue is very important in places like El Salvador and Honduras where the contribution of off-farm income to total rural income is significant (Berdegué *et al.*, 2000).

Previous studies of peasant agriculture have shown that household outputs can be classified into the following categories: subsistence crops; cash crops; livestock; and off-farm income (Coelli and Fleming, 2004; Chavas *et al.*, 2005; González and López, 2007). In our model, households are assumed to produce three outputs: *Staples*, represented by the value (US$) of the production of maize and beans; *Cash Crops*, which is the value (US$) of other crops and livestock[4] products produced in the household; and *Off-Farm Income* which includes wage labour earned (US$) on other households' farms and/or in off-farm activities by all the members of the household. Consistent with the literature on production economics, a rural household needs three essential inputs to generate these outputs: land; materials; and labour (Kumbhakar and Lovell, 2000). Our empirical model includes the following specific inputs: *Land* defined as the total cultivated area measured in Manzanas (1 Mz = 0.7 ha); *Purchased Inputs* given by the total expenditure (US$) on seeds, fertiliser, pesticides, hired animal power, as well as the expenditures necessary to implement the soil conservation practices promoted by PAES and CAJON on the farm (e.g. green mulch and seeds for non-traditional crop rotations); *Family Labour* measured as the total number of worker days that family members work in the farm; *Hired Labour* measured as the amount paid (US$) to hired workers; and *Off-Farm Labour* which is measured as the number of people in the household over the age of 15 years with off-farm jobs. The division of agricultural labour is consistent

[3] A similar rationale for including environmental variables in explaining TI can be found in Coelli and Perelman (1999) in their study of the European Airline industry.

[4] Livestock production is a minor activity in our dataset so it is combined with other crops.

with the view that in developing countries family and hired labour may not be perfect substitutes and thus should be treated as separate inputs (Taylor and Adelman, 2003).

Following Lindner (1987), we control for land quality by including the dummy variable *Slope*, which is equal to 1 if the average slope in the farm is greater than 15%. Finally, three dummy variables are included to account for possible project, location and/or environmental fixed effects (i.e. PAES 1, PAES 2 and PAES 3, with CAJON as the excluded category). In this study, PAES is treated as three separate projects as each one was executed by independent firms relying on their own methodologies. It is important to note that these four projects were implemented in different and non-overlapping geographic areas.

As indicated, the stochastic frontier methodology used in this study makes it possible to evaluate factors related with inefficiency. To do so, several socioeconomic and technical variables are incorporated into the model based on the literature and on data availability. To account for human capital we include *Age* defined as the age of the household head, and *Education* representing the average number of years of formal education completed by the all household members who are 15 years of age or older. The following variables are included to account for household characteristics: *Gender*, a dummy variable equal to 1 if the household head is a male; *Ownership*, a dummy variable equal to 1 if the household owns 50% or more of the cultivated land; and *Credit*, a dummy variable equal to 1 if the farmer has access to credit.[5] In addition, *Participation*, a dummy variable that is equal to 1 if the household head participates in a farmer or social organisation, is included as a proxy for social capital. Empirical studies have shown a positive effect of access to social networks and institutions on production and rural income (Winters *et al.*, 2004). To capture the direct impact of the projects on TI the following variables are included: *Extension*, the number of visits made by a project extension agent to the farm during the last agricultural year; and *Years*, the number of years that a farmer participated in the project under study.

Finally, the variable *Practices* is included to capture directly the impact of the level of adoption of soil conservation practices on TI. This variable is measured as the ratio of cultivated land under soil conservation practices (i.e. crop residue mulching, minimum tillage, crop rotation, green manure and/or contour tillage) to total cultivated land. As already indicated, *Practices* may be an endogenous variable because the decision to adopt soil conservation practices is likely to depend, for a given agricultural year, on unobservable variables that might also influence TI.[6] Consequently, an instrumental variables (IV) technique is used to correct for endogeneity. Specifically, the variable included in the TI model is the expected value of *Practices* obtained from the estimation of an adoption model. Because of the statistical characteristics of the dependent variable (i.e. a ratio), this model is estimated

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[5] In this study, access to credit is considered exogenous, a practice commonly adopted in the agricultural economics literature (e.g. Chavas *et al.*, 2005; Deininger *et al.*, 2004; among others). However, some studies have endogenised credit (e.g. Rios and Shively, 2006) while non-conclusive results about the endogeneity of credit (financial assistance) can be found in Davidova and Latruffe (2007).

[6] Our endogeneity assumption is supported by the results of the Durbin–Wu–Hausman test (Judge *et al.*, 1988).

using generalised least squares (GLS) in order to correct for heteroskedasticity. It is important to indicate that the selected instruments used to estimate the expected value of *Practices* display the desired attributes according to Grootendorst (2007). The results of this model are reported in Appendix 1.

It is worth noting that all the farms in the sample have at least 30% of their cultivated land under conservation technologies. Thus, the conservation variable *Practices* does not measure the difference between adopters and non-adopters but rather the impact of differential soil adoption conservation rates on TI. Furthermore, as the sample is limited to project beneficiaries, the self-selection bias that could be induced by the omission of non-adopters/non-beneficiaries does not arise.

The households included in this study were selected randomly from lists containing all beneficiaries associated with the PAES and CAJON projects available from the respective implementing units. The interviews were conducted between May and August 2002 and the survey included questions on the households' composition, socioeconomic characteristics and agricultural activities. The data from El Salvador have a total of 465 farm households (148 PAES 1, 162 PAES 2 and 155 PAES 3) drawn from a listing of all beneficiaries located in 102 communities of the Lempa River Watershed. In Honduras, 174 households selected from the 240 communities participating in the CAJON project were interviewed. Thus, the final dataset encompasses a total of 639 observations.[7]

Table 1 presents descriptive statistics by project for all the variables included in the analysis. In general, the typical project participant operates about 5.85 Mz (4.1 ha) and most of the farmers (74%) own more than 50% of the land they operate. They are middle-aged men (87%) and have very limited access to rural credit and formal education.

5. Results and Discussion

5.1. Input stochastic distance frontier

Table 2 presents the ML parameter estimates for the estimated ISDF model.[8] We have selected a translog functional form because preliminary analyses based on generalised likelihood ratio tests rejected the Cobb–Douglas in favour of the more flexible specification. Following common practice, all variables are normalised by their geometric mean (GM); thus, the first-order coefficients can be interpreted as partial production elasticities evaluated at the GM. It is useful to point out that, because of the structure of a distance function, the partial output elasticity corresponds to the negative of its estimated coefficient (Coelli and Perelman, 1999). Furthermore, in order to qualify as a well-behaved model, the ISDF needs to be non-decreasing in inputs and decreasing in outputs (Färe *et al.*, 1994; Sauer *et al.*, 2006). Table 2 shows that, at the GM, the estimated model satisfies these conditions except for the coefficient for *Hired Labour*, which is positive but not statistically different from zero.

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[7] For more details on the PAES and CAJON Project, the data and the sampling procedure, please refer to Bravo-Ureta *et al.* (2003).

[8] STATA 9.0 was used to estimate the stochastic distance frontier simultaneously with the TI effects model. It should be noted that comparable results were obtained from an output-oriented SDF and a stochastic production frontier (which was implemented using an aggregate output index).

Table 1

Descriptive statistics for the variables in the sample

	All		CAJON		PAES 1		PAES 2		PAES 3	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Outputs										
Staples	897.51	876.7	896.58	665.1	923.49	991.0	682.10	1,035.1	1,106.05	731.9
Cash	672.15	2,196.3	504.44	2,610.4	607.12	2,706.25	1,091.87	1,340.9	441.21	1,789.5
Off-Farm Income	540.97	1,015.1	555.46	1,336.6	519.46	788.9	560.11	788.9	526.2	935.4
Household Income	2,110.63	2,761.4	1,956.48	3,002.7	2,050.07	3,601.9	2,334.08	1,993.3	2,073.46	2,210.8
Inputs										
Land	5.85	13.4	3.80	21.2	5.39	12.5	9.27	7.97	4.56	3.12
Purchased Inputs	657.78	996.8	585.07	1,437.3	711.95	1,110.2	694.39	601.5	638.52	4,876
Family Labour	43.52	53.7	29.21	55.7	30.67	24.6	76.47	30.9	33.56	18.1
Hired Labour	20.26	33.4	13.8	12.3	14.10	16.8	35.85	78.4	15.31	12.3
Off-Farm Labour	3.01	2.00	2.41	1.81	2.30	1.89	5.61	3.24	2.56	1.41
Slope	0.61	–	0.51	–	0.57	–	0.75	–	0.59	–
Inefficiency term										
Age	47.99	15.5	48.34	13.2	48.50	15.4	46.25	15.1	49.06	15.2
Education	3.57	2.5	4.08	2.3	3.12	2.0	3.41	2.1	3.44	2.6
Gender	0.87	–	0.83	–	0.89	–	0.95	–	0.78	–
Extension	1.96	0.8	1.95	0.8	1.87	0.7	2.17	0.9	1.81	0.7
Years	3.11	0.9	2.85	0.9	2.62	0.8	4.10	1.0	2.75	0.8
Credit	0.26	–	0.18	–	0.27	–	0.37	–	0.2	–
Ownership	0.74	–	0.79	–	0.78	–	0.62	–	0.76	–
Participation	0.63	–	0.57	–	0.45	–	0.93	–	0.54	–
Practices	0.62	0.3	0.48	0.2	0.70	0.3	0.70	0.3	0.61	0.3
No. households	639		174		148		162		155	

Table 2

Maximum-likelihood estimates for the ISDF[a]

Variable	Coeff.	SE	Variable	Coeff.	SE
Constant	−4.83***	1.07	P. Inputs × F. Labour	0.01***	0.00
Staple	−0.25***	0.10	P. Inputs × H. Labour	−0.01	0.00
Cash	−0.49***	0.06	P. Inputs × O-F Labour	−0.00	0.00
Off-Farm Income	−0.36*	0.18	F. Labour × H. Labour	−0.00**	0.00
Land	(0.05)	–	F. Labour × O-F Labour	−0.02	0.08
Purchased Inputs	0.48**	0.24	H. Labour × O-F Labour	−0.02***	0.00
Family Labour	0.36**	0.15	Slope	0.00	0.02
Hired Labour	−0.10	0.22	PAES 1	0.25***	0.11
Off-Farm Labour	0.20*	0.13	PAES 2	0.34***	0.08
$(\text{Staples})^2$	−0.03***	0.00	PAES 3	0.29**	0.15
$(\text{Cash})^2$	−0.04***	0.00			
$(\text{O-F Inc})^2$	0.06***	0.00			
$(\text{Land})^2$	(0.06)	–	Inefficiency model		
$(\text{P. Inputs})^2$	0.09*	0.04			
$(\text{F. Labour})^2$	0.00	0.00	Constant	−2.51***	0.77
$(\text{H. Labour})^2$	−0.02***	0.00	Age	0.01	0.02
$(\text{O-F Labour})^2$	0.06***	0.00	Education	−0.30***	0.03
Staples × Cash	0.04*	0.03	Gender	−0.05**	0.01
Staples × O-F Inc	−0.08*	0.05	Extension	−0.10**	0.04
Staples × Land	(0.04)	–	Years	0.16	0.19
Staples × P. Inputs	−0.06**	0.03	Credit	−0.09	0.13
Staples × F. Labour	−0.00	0.00	Ownership	0.12***	0.01
Staples × H. Labour	0.00	0.04	Participation	−0.08*	0.05
Staples × O-F Labour	0.01***	0.00	Practices	−0.10***	0.02
Cash × O-F Inc	0.07**	0.03			
Cash × Land	(−0.09)	–	$\sigma^2 = \sigma_v^2 + \sigma_u^2$	0.09***	0.02
Cash × P. Inputs	−0.03	0.03	$\gamma = \sigma_u^2 / \sigma^2$	0.62***	0.15
Cash × F. Labour	0.070***	0.02	Log-likelihood	−500.42	
Cash × H. Labour	0.003**	0.00			
Cash × O-F Labour	0.05	0.17			
O-F Inc × Land	(−0.05)	–			
O-F Inc × P. Inputs	−0.003	0.00			
O-F Inc × F. Labour	0.01**	0.00			
O-F Inc × H. Labour	0.002	0.00			
O-F Inc × O-F Labour	0.04	0.06			
Land × P. Inputs	(−0.08)	–			
Land × F. Labour	(0.02)	–			
Land × H. Labour	(0.01)	–			
Land × O-F Labour	(−0.01)	–			

***Notes*:** *10% level of significance, ** 5% level of significance, ***1% level of significance.
[a]Parameters in parenthesis are computed by the homogeneity condition.

The values for the parameters σ^2 and γ are reported at the end of Table 2. The parameter γ is statistically significant at the 1% level, with an estimated value of 0.62. These results indicate that inefficiency is highly significant among the studied households. In addition, the null hypothesis that $\gamma = 0$ is rejected, confirming that TI is stochastic.

All coefficients for the project dummy variables suggest that farmers associated with PAES (1, 2 and 3) exhibit greater productivity than those working with CAJON. A possible explanation for this result might be found in the strategies used by these projects to promote the adoption of conservation technologies and more diversified production systems. PAES introduced an array of incentives, such as subsidies and cost sharing mechanisms, to assist its farmers, while the major strategy of CAJON was subsidised extension programmes. However, additional data and further research would be required to get a better understanding of the effect of the subsidies used in the different projects.

Table 3 presents the partial production elasticities and returns to scale (RTS) for the estimated model. Since this model was estimated using a translog specification, the magnitude of these measures varies across different points in the dataset. Thus, the elasticities and RTS are evaluated at the GM of the sample and at one standard deviation above/below (+SD/−SD) the sample mean. The magnitude and sign of these measures reflect important structural features of hillside peasant agriculture in El Salvador and Honduras. For instance, the estimated partial elasticities show that *Purchased Inputs* and *Family Labour* contribute the most to household production.

At the mean of the data, the partial elasticity for *Purchased Inputs* is 0.48 and this elasticity decreases as the value of the variable increases. These results indicate that *Purchased Inputs* have a higher impact on productivity among farmers that use these items at a lower level. This result is consistent with Kalirajan's (1991) finding that budget constraints can oblige peasant-farmers to employ sub-optimal amounts of inputs.

Family Labour and *Off-Farm Labour* exhibit positive, relatively large and increasing partial production elasticities, indicating that both inputs have a positive impact on total household productivity. In contrast, the parameters for *Hired Labour* are not significant. It is interesting to point out that the parameter for *Off-Farm Income* is statistically significant at the 10% level with a partial elasticity at the GM equal

Table 3

Partial elasticities and returns to scale[a,b,c]

Variables	−SD	MEAN	+SD
Staple	0.26	0.25	0.28
Cash	0.59	0.49	0.41
Off-Farm Income	0.34	0.36	0.37
Land	(0.04)	(0.05)	(0.07)
Purchased Inputs	0.49	0.48	0.38
Family Labour	0.27	0.36	0.40
Hired Labour	−0.16	−0.10	−0.03
Off-Farm Labour	0.18	0.20	0.22
RTS[d]	*0.84*	*0.90*	*0.94*

Notes: [a]The partial elasticities and returns to scale are measured at the geometric mean of the sample (MEAN), and at one standard deviation below (−SD) and above (+SD) the sample means.
[b]The partial output elasticity corresponds to the negative of its estimated coefficient.
[c]Parameters in parentheses are computed by the homogeneity condition.
[d]The RTS correspond to the inverse of the sum of output elasticities (Coelli and Perelman, 1999).

to 0.36, which provides some evidence of the importance of off-farm earnings on household productivity in rural Central America.

Land exhibits a positive but low partial elasticity. We note here that, because of the structure of the ISDF, the elasticity for *Land* is computed based on the homogeneity condition. Several previous studies relying on the ISDF have also used *Land* to normalise the ISDF but they have not calculated the elasticity for this variable (e.g. Coelli and Fleming, 2004; González and López, 2007). However, Morrison Paul *et al.* (2000), who also implemented an ISDF in their paper on sheep and beef farming in New Zealand, obtained negative elasticities for land. Low elasticities for land have also been reported by other authors using stochastic production frontiers, including Wilson *et al.* (2001) and Cuesta (2000).

Table 3 also shows that, at the GM, the calculated RTS is 0.90, revealing the presence of decreasing returns to scale (DRTS). According to Chavas *et al.* (2005), the presence of DRTS in multi-output multi-input farm household models implies that the quantities of some inputs exceed the scale efficient point. González and López (2007) also found DRTS using multi-input and multi-output models among peasant farmers in Colombia.

To analyse the effect of output diversification on household production we estimate indices of diversification economies (DEs) using the estimated ISDF parameters. Indices of DEs reflect the gain or loss in total output achievable from the reallocation of resources among different products (Morrison Paul *et al.*, 2000; Coelli and Fleming, 2004). In this context, DEs are measured as the second derivative of the ISDF with respect to outputs (Coelli and Fleming, 2004). More precisely, if the DE index for a pair of outputs is positive then an increase in one raises the marginal product of the other, suggesting that the two outputs are complements. By contrast, a negative sign implies substitutability.

Using the parameters presented in Table 2, the DE indices calculated for each pair of outputs are as follows: −0.08 for the combination of staple production and off-farm income; 0.04 for staple and cash crops; and 0.07 for cash crops and off-farm income. The negative values obtained for the pair staple production and off-farm income suggest that these outputs are substitutes; hence, farms engaged mainly in staple production (maize and corn) would find it difficult to achieve productivity gains by pursuing off-farm activities as a strategy to diversify household income. However, DEs are positive between cash crops and off-farm income, and between staple production and cash crops. Thus, cash-crop households could expect gains in productivity by engaging in (additional) off-farm activities and staple oriented households could improve productivity by diversifying towards cash crops.

5.2. Technical efficiency

As shown in Table 4, the mean TE is 78% suggesting considerable inefficiency levels among the studied households. Specifically, many farms in the sample could, in principle, reduce inputs significantly and still generate the same level of outputs. Table 4 also presents the distribution of TE scores. This table shows that approximately 76% of the farmers achieve TE levels of 70% or higher. It is worth noting that the average level of efficiency obtained here is comparable with the averages presented by Bravo-Ureta *et al.* (2007) in their meta-regression analysis of TE in agriculture. In fact, these authors report a 78% average TE for stochastic frontier studies focusing on Latin America.

Table 4
Distribution of technical efficiency scores

TE interval (%)	% of farms in TE interval
0–10	0.7
11–20	1.1
21–30	1.2
31–40	1.5
41–50	5.7
51–60	5.7
61–70	7.8
71–80	13.7
81–90	51.2
91–100	11.3
Mean TE	78

The results of the TI estimates are presented at the end of Table 2. Following common practice, the interpretation of the parameters is performed with respect to their effect on TE, which means that the estimated coefficients are analysed as if they displayed the inverse sign. *Education* and *Extension* present positive and significant effects on household efficiency, and the parameter for the former variable is the largest. These results support the premise that increases in human capital enable rural households to improve resource utilisation and thus achieve higher productivity.

The estimated model suggests that non-owners are more efficient than owners. This result contradicts the commonly held idea that, *ceteris paribus*, land ownership reduces risk and, consequently, should enhance expected returns and encourage farmers to invest in more productive technologies (Gebremedhin and Swinton, 2003). However, several empirical studies have reported a negative association between land ownership and farm efficiency (e.g. Byiringiro and Reardon, 1996; Binam *et al*., 2003; Deininger *et al*., 2004). Nevertheless, this result is consistent with the fact that non-owners have added cash outflow requirements to cover land rental and this could act as an incentive to be more efficient.

The variable *Gender* presents positive and statistically significant effects on TE suggesting that male-headed households are more efficient than their female counterparts. González (2004) contends that lower levels of efficiency among female-headed households could stem from gender inequities in rural Latin America, where women have more difficult access to land, capital and/or other financial services. The gender difference could also stem from unmeasured outputs generated by females in the household. Generally, female household-heads are not only in charge of their family business but they are also responsible for taking care of basic household needs (child rearing and care, cooking, cleaning, etc.). These activities are difficult to quantify but they do compete for women's time and effort. To test this hypothesis, detailed intra-household information is required, which is not available for this study. This is clearly an area that merits further research.

The association between *Participation* and TE is positive and statistically significant. This result concurs with those of Winters *et al*. (2004), who conclude that social capital has an important role in poor developing rural societies. Conversely, the parameters for *Credit*, *Age* and *Years* are not statistically different from zero.

Finally, an important goal of this study is to evaluate explicitly the association between the adoption of soil conservation practices and farm efficiency. As explained earlier, the decision to adopt such practices is seen as a choice variable for the farmer and thus it is expected to be endogenous in the TI part of the frontier model. Thus, an IV approach is used and the predicted value of *Practices* is included as an explanatory variable in the TI equation. As shown in Table 2, the parameter for the predicted value of *Practices* is negative and significant, which reveals a positive association between TE and adoption of soil conservation practices. Otsuki *et al.* (2002) indicate that many rural policies in Latin America have been conceived to promote economic development but usually have had costly environmental effects. However, our results support the hypothesis that the adoption of soil conservation is not only a good tool for controlling environmental degradation but is also associated with higher farm efficiency. Thus, a crucial funding of this study is that economic and environmental sustainability can be complementary rather than competitive goals.

6. Concluding Remarks

The main hypothesis of this study is that improvements in TE are not only financially beneficial to farm households but can also contribute to environmental sustainability. To examine this proposition, this study analysed the structure of the production technology and sought to explain the variability in TE for a sample of hillside farmers in El Salvador and Honduras using input-oriented stochastic distance frontiers. The estimated model showed significant levels of TI among the sampled households, which suggests that opportunity exists to expand household production using the current level of inputs and the technologies already available in the regions included in this study. In addition, the conservation technologies promoted in El Salvador and Honduras show a positive association with TE which is consistent with the proposition that productivity gains are compatible with environmental sustainability.

The empirical results indicate that human capital, measured by years of schooling and farm extension visits, is a key factor associated with higher levels of TE. The statistical significance of the parameters associated with these variables in all estimated models is not surprising since the average level of formal education among the sampled households is only 3.6 years. This result is in line with the arguments made by Sen (2000) who indicates that investments in human capital provide the greatest returns in terms of socioeconomic development. Therefore, rural development and natural resource management programmes in Central America should strengthen efforts designed to increase the level of knowledge among small farmers.

In addition, the production and environmental measures promoted by PAES and CAJON show a positive association with TE. Specifically, our findings show that diversifying the sources of household income is an effective strategy to improve environmental conditions at the farm level as well as to increase the wellbeing of small hillside farms in Central America. The results also suggest that for households that have a more diversified farm production plan, off-farm work can contribute to household productivity. Conversely, crop diversification seems to be a desirable path for producers of subsistence crops. The analysis also reveals that the adoption of soil conservation practices has a positive and significant association with TE. This outcome is important in analysing the sustainability of natural resource management projects in less-favoured areas because some technologies can be effective in decreasing environmental degradation, but their adoption could be limited if they do not bring tangible economic benefits to farmers.

Finally, our findings are particularly relevant in the design of resource management and poverty alleviation strategies for less-favourable areas. For years, researchers have argued that the most important factor preventing the achievement of sustainable economic development in many low-income countries is the vicious cycle of rural poverty which forces farmers to overuse their land leading to its degradation followed by lower agricultural productivity, more poverty and so on (Meier and Rauch, 2000). In the preceding analysis we have found empirical evidence indicating that policies directed to controlling farm-level land degradation and to supporting human capital formation can also improve agricultural efficiency. Higher efficiency gives subsistence farmers the opportunity not only to produce the current level of outputs with less inputs, but also allows them to free up some of their land which can then be shifted towards cash crops and thus a more diversified income stream. Implementing such an option can enhance household liquidity and can gradually open up further opportunities which could redress the vicious circle of rural poverty. This strategy, however, also requires that explicit attention be given to facilitating market access to peasant farmers for their growing and diversified output mix.

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Appendix 1

Table A1

GLS Estimates for the Adoption of Conservation Practices

Variable[a]	Coefficient	SE
Constant	0.04**	0.02
Land	0.10**	0.05
Slope	0.06*	0.03
Perception[b]	0.25***	0.03
rho (IV, Practices)[c]	0.65**	
No. observations	639	

***Notes*:** *10%, ** 5% and ***1% level of significance.
[a]The dependent variable is the ratio of cultivated land under soil conservation practices.
[b]Perception is a dummy variable equal to 1 if a farmer perceives soil erosion as a problem in his/her farm and 0 otherwise.
[c]Spearman correlation.