Soil Degradation and Technical Efficiency in Shifting Cultivation: The Case of Yucatán (Mexico)

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Abstract

Identification of technical inefficiencies can be helpful for policy-makers aiming at conserving the productive potential of fragile agroecological areas, without negatively affecting the users of the natural resource base. This is the case in areas where traditional forms of shifting cultivation is practiced. The reason being that the reduction in the 'slash-and-burn' of forest vegetation biomass could reverse the negative environmental externalities both at the local (e.g., reductions in crop yields) and global (e.g., increases in carbon emissions) levels.
By using household level data from the Yucatán (Mexico), this paper empirically analyses traditional shifting cultivation (slash-and-burn) technology by allowing for random inefficiency factors. The analysis is based on the application of a Stochastic Production Frontier (SPF) model that is non-neutral in natural capital. In addition to various household-demographic variables, the analysis can tell whether off-farm labour allocation has any impact on crop production through its effect on technical efficiency. Similarly, the way poverty might affect crop production (indirectly by determining the managerial ability in production) is described. The importance of the answers lies in the insight that is given into the link between soil degradation, and poverty and off-farm labour supply in fragile agroecological systems. Besides a relatively large scope for improving efficiency, the results of the paper indicate that poverty impedes increasing managerial ability and that lower natural capital although constraining frontier production, induces farmers to increase their level of managerial efficiency in crop production. These results have direct policy implications for rural development and natural resource conservation in many rural regions of the developing world.

Keywords: Technical efficiency, shifting cultivation (milpa), soil degradation, Yucatán, Mexico.

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1 Introduction

The neoclassical theory of the farm household, indicates that households will use all available inputs under their control in a manner that is technically efficient, conditional upon producer information and managerial ability. Market signals, through product and input prices (including labour), and market competition for these scarce resources is viewed as the avenue for their efficient allocative behaviour. In 'real life', however, this process works slowly, and information access and utilisation fails to guide all farm households to the same technically efficient frontier. When technical inefficiency (TI, henceforth) exists in production, there is an opportunity to curtail input use without negatively affecting crop production. Such opportunities are of particular interest for the rural poor who are limited in assets (financial, human and natural) given that they could substitute 'excessive' allocation on-farm labour time for off-farm labour and thus increase their income level. In addition, identification of technical inefficiencies can be helpful for policy-makers aiming at conserving the productive potential of fragile agroecological areas, without negatively affecting the agricultural users of the natural resource base. The reason being that input reductions (e.g., in forest-vegetation complex) could lead to reverse negative environmental externality effects on the production process.

It is often assumed that factors affecting farm households' technical efficiency (TE henceforth) are due to their demographic and socio-economic characteristics. Nevertheless, these affects are 'a priori' largely unknown. In addition, controlling for input quality (and not just quantity) is important when deriving TE measures. Farrell noted that in the context of agriculture, if there are differences between farmers concerning the soil quality they use, and if this is not controlled for, then "[...] it is never possible to decide precisely how far the fertility of a particular farmer's land is due to nature and how far to good husbandry" (Farrell 1957). Controlling for soil quality then, is necessary to obtain 'genuine' TE scores. In a review of TE studies applied to agriculture Coelli has recognised that "[...] the possibility that unaccounted for environmental factors, such as soil quality, may also influence technical efficiency measures" (Coelli 1995).

Given the widespread phenomenon of shifting cultivation in tropical regions of the developing world, it is surprising that so little attention has been paid to the potential linkages between soil quality and TE in these traditional farming systems.[1] Inspired by Jaenicke and Legnik (1999), this paper is concerned with the assessment of the effect of changes in soil quality levels on shifting cultivator's

[1] Shifting cultivation in forested areas consists of clearing patches of primary or second-growth forest, by cutting down the tree-bush above-ground vegetation and burning as much of the woody biomass as possible. Crops are then planted among the charred stumps. By burning the above-ground biomass, the cleared land usually becomes free from weeds and the soil has an additional reserve of plant nutrients through the ashes of the burned forest vegetation material.

TE. The outcome of the analysis is relevant for policy making in Yucatán, since, on the one hand, it can uncover the ongoing relationship between labour and natural capital in most shifting cultivation communities. It can also assess the role of soil quality and relevant demographic (e.g., education) and socio-economic (e.g., poverty levels) factors affecting the agricultural performance of peasants that produce most of staple crop, specifically maize, in most of South Mexico.

The paper is organised as follows: The next section reviews the relevant literature. Section 3 outlines the technical efficiency model. Section 4 gives a background to the case study from Yucatán and section 5 illustrates the results of applying a non-neutral stochastic production model using data from 74 shifting cultivating households. Finally, section 6 points out the main results of the empirical analysis and discusses some policy implications.

2 A review of the literature:

Since the Schultzian 'poor but efficient' hypothesis, many attempts have been made to assess peasants' efficiency (both technical and allocative) in developing country agriculture. The first attempts at measuring efficiency by farm households in developing countries came with the work by e.g., Chennareddy (1967) and Sahota (1968) who were concerned with measuring efficiency of Indian agriculture. Lau and Yotopoulos (1971) using a dual profit function model assessed both technical and allocative efficiency of Indian farmers alike.[2] During that time, a very influential separate body of TE measurement method was being developed based upon Farrel's (1957) seminal work which in turn drew upon work by Debreu (1951) and Koopmans (1951). This method, generally known as frontier analysis, has evolved through the years generating considerable progress in the theoretical foundations of TE measurement indexes and has propelled a vast amount of applied work both in developed and developing countries to assess performance of the agricultural sector, among others. Notwithstanding the potential use of non-stochastic and non-parametric Data Envelopment Analysis approach for TE measurement, this paper focuses on the stochastic and parametric frontier analysis, called Stochastic Production Frontier (SPF) approach.[3]

Surprisingly, the empirical application of TE analysis in the field of environmental economics is scarce. Most work in this area has to do with agriculture taking natural resources as exogenous variables. For instance, Sherlund et al. (1998) have analysed the role of exogenous natural produc-

[2] The way Lau and Yotopoulos (1971) compared between inter-firm TE was by using a Cobb-Douglas production function, and then comparing the value of the intercept term.

[3] See Bravo-Ureta and Pinheiro (1993) and Bravo-Ureta et al. (2000) for a recent follow up of SPF analysis applied in the context of developing country agriculture. A DEA approach has been also used elsewhere by the author. This paper just focuses on SPF analysis.

tion conditions (e.g., soil quality, rainfall, weed growth) when assessing the TE of rice farmers from the Ivory Coast. They found that when exogenous environmental factors are not accounted for inefficiency estimates are usually overestimated by seriously biasing the parameters of the frontier technology. Similarly, Tadesse and Krishnamoorthy (1997) found that controlling for agroecological zones is important from a policy standpoint due to differing efficiency levels in paddy farms in India. In another study, Otsuki and Reis (1999) found that land tenure affects TE in the joint production of timber and agricultural crops in the Brazilian Amazon. Piot-Lepetite et al. (1997) estimated the potential negative external effects of the excessive (or inefficient) application of polluting inputs (i.e., fertilisers and pesticides) on agricultural soil of French cereal farms. In a similar line of enquiry, Hadri and Whittaker (1999) assessed the effect of soil pollution on crop TE, and found a positive relationship between TE and use of contaminants in a sample of farms in South West England. In a step forward, Jaenicke and Legnik (1999) can be considered to be the most fruitful analysis to date. Their innovative approach is based on using Farrell's TE notion by using distance functions to disentangle the effects of different physical soil properties on TE in order to assess their potential role in crop production, therefore being able to define a practical context-specific and multidimensional 'soil quality' concept.

3 A model of TE in shifting cultivation

The most important advantage of SPF approach is that in contrast to non-parametric approaches (such as Data Envelopment Analysis), it allows for the introduction statistical noise resulting from natural events outside economic agents' control. In our case, for instance the amount and timing of rainfall and damage to maize stalks done by birds and rodents in shifting cultivation.

The SPF treats the disturbance term of a regression describing a crop production function (ϵ), as being 'composed' by a standard independent statistical noise term (v) and a one-sided non-negative random disturbance (u), i.e., $\epsilon = v - u$. The white noise component,v, that accounts for non idiosyncratic random effects, stands for a symmetric error term assumed to be independently and identically distributed (iid) as $N(0, \sigma_v^2)$. The second error term, u, represents systematic effects that are not explained by the production function and therefore are attributed to households' TI. This inefficient effect term u is one-sided since if $u = 0$, the household would be lying on the production frontier, obtaining maximum production given the levels of inputs whereas if $u > 0$ then, the household would be operating at some level of TI. The inefficiency effect term is usually assumed to follow a 'half normal' distributional form, i.e., iid $N|(0, \sigma_u^2)|$ that is a restricted form of a more flexible truncated normal distribution $N(\mu, \sigma_u^2)$, where $\mu > 0$.[4]

[4]Other distribution forms are: the 'exponential' which in turn is a restricted form of the more flexible 'two-

Following Farrell's (1957) TE notion, a measure of TE for any given household i would be given by the following ratio:

$$TE_i{}^T = \frac{E(\mathbf{z}_i|\mathbf{u}_i, \mathbf{x}_i)}{E(\mathbf{z}_i|\mathbf{u}_i = 0, \mathbf{x}_i)} \tag{1}$$

where $\mathbf{z}_i$, $\mathbf{x}_i$ and $\mathbf{u}_i$ are the output, input and inefficiency effect vectors, respectively. In turn, the general stochastic frontier production function is usually defined by:

$$\mathbf{z}_i = F(\mathbf{x}_i; \beta)\; e^{(\mathbf{v}_i - \mathbf{u}_i)} \tag{2}$$

where $\mathbf{z}_i$ is a (1×1) scalar describing the quantity of crop output for household i; $\mathbf{x}_i$ is an $(n+1)$ row vector where the first element, "1", represents the intercept and the remaining elements represent quantities of inputs employed to produce $\mathbf{z}$; β is an $(n+1)$ column vector of technology parameters to be estimated; $\mathbf{v}_i$ and $\mathbf{u}_i$ are the (1×1) error components defined above. Hence, the stochastic production frontier, as defined in (2), is determined by the structure of the technology of production, i.e., the deterministic production frontier given by $F(\cdot)$, and in addition by external factors to the production process including household specific inefficiency effects. It follows that a TE index for a given household i, is given by:

$$TE_i{}^T = \frac{\mathbf{z}_i}{\mathbf{z}_i{}^*} = \frac{F(\mathbf{x}_i; \beta)e^{(\mathbf{v}_i - \mathbf{u}_i)}}{F(\mathbf{x}_i; \beta)e^{\mathbf{v}_i}} = e^{-u_i} \qquad \text{(so that } 0 \leq TE_i{}^T \leq 1) \tag{3}$$

where $z_i{}^*$ stands for the frontier output. To readily use (3), the TI factor u_i must be separated from the white noise in the composed error term ϵ. The household-specific representation of conditional inefficiency, $\mathbf{u}|\epsilon$, for each observation can be derived from the conditional distribution of $\mathbf{u}$ (Jondrow et al. 1982).[5]

It is worth noting at this point that standard production function might fail to capture inefficiencies associated with different factor endowments since it is implicitly assumed that $\epsilon = v$. The production function so obtained would be descriptive of reality only if the assumption of efficient choice is a good approximation of reality (Koopmans 1951). In this respect, a SPF function under positive levels of inefficiency can be said to be superior to a standard production function because the latter omits a potentially important explanatory factor by disregarding the error term u.

Koopmans (1951) pointed out that the quality characteristics of the available factors and of the desired product specifies the variables entering in the production function, and that the available quantities of the factors specify the values of these variables. Here, the quality of the land used

parameter Gamma' distribution (Green 1993). A fortiori, the resulting TE measures are not invariant to the choice of TE distribution (Bauer 1990).

[5]Equation (3) implies that the TE index for any given household is positive and no greater than one. The reciprocal of this quantity, $\exp(u_i)$, is no less than one, and can be interpreted as a measure of the technical inefficiency in crop production. More precisely, the amount by which $\exp(u_i)$ exceeds one is a measure of TI (Battese et al. 2000). It gives the proportion by which the actual crop output can be increased holding the input use unaltered.

for cultivation (expressed through an index of fertility) is explicitly accounted for as a factor of production, together with the newly cleared fallowed forest land area and the labour applied on that land after having slashed and burned the aboveground forest vegetation in a forest plot. The shifting cultivation crop production technology is captured by the following equation:

$$z_i = f_i \left[g\, L_i/b_i, (1-g)L, Q_i \right] \tag{4}$$

where the arguments in the production technology are: the area of new cleared forest land, $g\, L/b$, labour used in crop production on this land, $(1-g)L$, and soil quality, Q. New cleared land is in turn a function of (i) total labour allocated on-farm, L, (ii) the proportion of that labour dedicated to clearing new forest land, g, and (iii) a measure of labour intensity in forest land clearing, i.e., the amount of on-farm labour needed to clear a unit of forest land, b. By extension, the second argument in the crop production function (4), is 'cropping labour', i.e., the proportion, $1-g$, of on-farm labour allocated to tasks other than forest clearing, such as sowing and weeding.

It is convenient to approximate the frontier production base on the technology represented in equation (4) and (2) by a simple mathematical function. Here $F(\cdot)$ follows a Cobb-Douglas (CD) functional form. According to Bravo-Ureta et al. (2000), out of 27 SPF-type journal articles concerned with developing country agriculture, 13 have used CD while 14 have used the alternative translog specification.[6]

The CD technology is described as follows:

$$\mathbf{z}_i = \beta_0 \prod_{j=1}^{n} x_{ij}^{\beta_j} e_i^{\epsilon} \tag{5a}$$

or in log-linear form:

$$\ln \mathbf{z}_i = \beta_0 + \beta_j \sum_{j=1}^{n} \ln x_{ij} + v_i - u_i \tag{5b}$$

where $\epsilon_i = v_i - u_i$ and the subscripts i and j index for households and inputs respectively. Here, we follow Battese and Coelli (1995) by assuming that the TI factor, denoted u_i, is comprised of non-negative random variables that are assumed to be independently distributed as truncations (at zero) of the $N(\mu_i, {\sigma_u}^2)$ distribution. In recent advancements of SPF-TE methodologies, μ_i

[6] The CD function was preferred due to the severe multicollinearity introduced by the interaction terms in the translog. In all parametric analysis, the choice of a right functional form arises as an important empirical matter, however it is not clear how the functional form affects the final estimated score of TE. While Bravo-Ureta and Pinheiro (1993) and Green (1993) have pointed out that the sensitivity of the efficiency measures to the choice of functional form is rather small and that the frontier parameter estimates may be equivalent to those obtained from a more general translog specification at the sample mean, in a more recent (meta) analysis of 35 technical efficiency studies published in leading international journals, Bravo-Ureta et al. (2000) suspect that the CD functional form might yield lower average TE scores than alternative translog specifications.

is approximated (in a simultaneous way) by a multiple linear regression with household specific variables as independent regressors. For household i the 'TI effects' (TIE) model is defined by:

$$u_i = \delta_0 + \sum_{j=1}^{m} \delta_j s_{ij} + w_i \tag{5c}$$

where, the s_i are factors that may influence the efficiency of the sample households, δ is a vector of parameters to be estimated and w_i is an independently distributed unobservable random variable, obtained by truncation of the normal distribution with mean zero and unknown variance, ${\sigma_u}^2$, such that u_i is non negative, i.e., $w_i \geq -(\delta_0 + \sum_{j=1}^{m} \delta_j s_{ij})$.

Due to the interest in linking the level of soil quality and TE in shifting cultivation, we follow a recent empirical development in the TE analysis literature by Huang and Lui (1994). The new approach is to use a 'non-neutral' stochastic frontier production where the inefficiency effects are functions of the some of one or more factor inputs themselves.[7] This model has been recently applied by Coelli and Battese (1996) and Bakhshoodeh and Thomson (2001) in the context of small-scale farming in developing countries to analyse the relationship between farm size and TE by using farm size as input factor and as a TI effect shifter. The idea here is to use soil quality both as an input in frontier production and as a factor affecting TE. To do so, the TIE model is defined by equations (5b) and

$$u_i = \rho_0 + \sum_{j=1}^{m} \delta_j s_{ij} + \delta_Q Q_i + w_i \tag{5d}$$

The following stochastic production frontier models are estimated:[8]

SPF1: a stochastic production frontier model without 'TI Effects' model. This is the Aigner, Lovell and Schmidt (1977) model expressed by equation (5b), and

[7]The Coelli and Battese (1996) model is a special case of a more complex stochastic frontier production by Huang and Lui (1994).

[8]A remark about the stochastic specification of the frontier production model is appropriate at this point. Production function models assume that the white noise error resulting largely from 'acts of nature', is unknown to the farmer in advance of input decisions (Zellner et al. 1966). Undoubtedly, the success of shifting cultivation is largely dependent on the knowledge of the natural system. For instance, given that it is a rainfed system, it is important to be able to predict adequate rainfall in order to start with the planting season. Although rainfall is often considered to be white noise, and therefore belongs to v, the ability to predict it, from farming experience, appears in u. Therefore, the ability to anticipate the weather after the 'first rains', and hence be able to change the optimum allocation of labour use, would be an empirical problem if a proxy for farming experience was not accounted for in the TIE model. This is because inefficiency (derived through algebraic manipulation of u) by household specific variables can be explained by the average age of the household (among other things) as a proxy for farming experience. At the same time, managerial ability, being an unobservable input factor, would be uncorrelated with the white noise (i.e., timing of rainfall).

SPF2: a 'Non-neutral stochastic production frontier model with TIE' given by the system of equations (5b) and (5d).

4 A case study from a municipality of Yucatán

The TE analysis has been carried out using household data collected during the 1997-98 agricultural year from the municipality of Hocaba in the Yucatán, Mexico. The municipality (MH) is named after the municipal seat, Hocaba. MH also contains the Sahcaba ejido. The Hocaba ejido contains approximately 5,000 households and occupies a total land area of 5,920 hectares (ha). The Sahcaba ejido comprises 1,500 households and 1,381 ha of land. Both communities are well connected by road to the State capital, Mérida, which is 55 kilometers (km) to the north.

There are several reasons why the Yucatán, and the Municipality of Hocaba in particular, is a good case study for application of the study. First, the Yucatán is considered to be within one of three main focal areas of deforestation in Mexico (Deininger and Minten 1999). Second, traditional shifting cultivation based on the traditional staple maize crop (referred to locally as "milpa") is the prevalent farming practice in the ejido communities of MH. In fact, throughout the state of Yucatán, virtually all of the 180,000 ha of agricultural land are farmed using shifting cultivation (Bautista and Jiménez 1999). Third, the common property land ownership, or ejido, system is the prevalent land tenure system in the Yucatán. Ownership by ejidos accounts for 56% of the total land area in the state (Thompson and Wilson 1994). Fourth, rural poverty is widespread in the Yucatán. An estimated 41.6% of the rural population in the Yucatán State is considered poor according to Mexican official institutions (see: INEGI 1990 and SEDESOL 1999). Fifth, in the MH case study site, many shifting cultivating households depend on off-farm employment to supplement their income and as a survival strategy. Finally, there is evidence that many milpa-based shifting cultivation systems in the Yucatán are close to ecological collapse, given current levels of population density in the state (Ewell 1984; Terán and Rasmussen 1994; Mizrahi et al. 1995).[9]

The information gathered from 74 peasant households were of two distinct nature (i) demographic and socio-economic data, including labour time applied in the different tasks of shifting cultivation, and (ii) agroecological data. The field data suggest that none of the surveyed households were able to supply any marketable surplus of the main crop, maize (*Zea Mays*), due to the very low yields from shifting cultivation. At best, milpa appears to be a secondary source of income for peasant households in MH. The fieldwork has also revealed that around 23% of peasant households

[9]Concerning the agroecological context, the MH is under a warm and sub-humid climatic influence with a dry season from October to May and an average annual precipitation of 978 mm (Mizrahi et al. 1995). The implication is that the natural vegetation is mainly made up of a low and medium tropical dry deciduous forest.

are below the official poverty line based on the minimum income threshold of 2,376 $ per capita annually (adjusted for Rothbarth's adult equivalency).

Table 1 presents the variables used in the empirical analysis. Among them special attention is paid to the soil quality indicator which has been restricted to lie between 0 and 1. This soil quality index derives from an agroecological study of around 900 soil samples (Pascual 2000) linking aboveground forest vegetation biomass (and thus natural forest fallow periods) with the potentially mineralisable nitrogen in the soil given that the stock of mineral nitrogen is critical for the development of maize (and other crops).

Table 1: Data definitions and descriptive statistics

Variable	Description	Sample Mean	Standard Deviation	Min.	Max.
	Total Output				
z	Kg.	635.50	488.73	23.76	2421.73
	Inputs				
L/a	New cleared land area (Ha.)	1.01	0.67	0.00	3.00
$(1-g)L$	Cropping labour (Hours)	260.18	203.79	18.00	880.00
Q	Soil Quality Index (0-1)	0.45	0.09	0.21	0.63
	TIE Independent variables				
AGEHoH	Age by HoH[a]	53.26	10.97	31.00	82.00
AGERoH	Average age by RoH[b]	33.19	9.42	16.52	60.00
EDUHoH	Schooling years by HoH	2.74	2.40	0.00	9.00
EDURoH	Average formal schooling years by RoH	4.21	2.07	0.00	10.50
OFLHOH	Hours off-farm by HoH	713.89	918.95	0.00	3360.00
OFLROH	Hours off-farm by RoH	763.90	747.16	0.00	2879.99
PMENRoH	Percentage of active males in RoH	67.15	15.20	16.66	100.00
Dummy variables:					
DUSUPHoH	1 if HoH supplies OFL; 0 otherwise	0.595	0.494	0.00	1.00
DUSUPRoH	1 if RoH supplies OFL; 0 otherwise	0.649	0.481	0.00	1.00
DLOC	1 if household is from Hocaba; 0 otherwise	0.662	0.476	0.00	1.00
QPRIVATE	1 if HH crops in its owned land; 0 otherwise	0.12	0.32	0.00	1.00
POVR1	1 if household income< 2376 Mex $	0.230	0.424	0.00	1.00

[a]: Head of the household (usually the eldest fit male

[b]: Rest of (active member) the household (members between 16 and 65 years old

5 The empirical results

The estimated production elasticities from models SPF1 and SPF2 can all be compared with mean output response elasticities. The difference with the standard mean production function approach is that using SPF we can test the existence of TE. Results concerning the frontier elasticities of SPF1 and SPF2 are presented in table 2 together with their variance parameter estimates $\sigma^2 = {\sigma_u}^2 + {\sigma_v}^2$ and $\gamma = {\sigma_u}^2/\sigma^2$.[10]

Table 2: ML estimates for stochastic production frontier models

Model		**MPF**	**SPF1**	**SPF2**
INTERCEPT	β_0	2.395^{***} (2.275)	5.326^{***} (8.546)	6.120^{***} (7.840)
L/a	β_1	1.166^{***} (3.525)	0.978^{***} (3.550)	1.022^{***} (4.185)
$(1-g)L$	β_2	0.249^{**} (2.651)	0.255^{***} (2.786)	0.097 (0.897)
Q	β_3	0.452 (1.606)	0.560^{*} (1.729)	0.915^{**} (2.901)
Variance parameters				
$\sigma^2 = {\sigma_u}^2 + {\sigma_v}^2$			0.170 (0.981)	0.349^{***} (4.974)
$\gamma = \frac{{\sigma_u}^2}{{\sigma_u}^2+{\sigma_v}^2}$			0.072 (0.288)	0.343 (3.473)
Non-neutral inefficiency effects:				
ln(*SOIL QUALITY*)	δ_{13}			1.370^{*} (1.887)
Loglikelihood function		74.66	73.27	55.27

Number of Observations: 74

The results of testing various null hypotheses for the specification of the models are shown in table 3.[11] The first null hypothesis, $H_0 : \beta_k = 0,\ k = 1...3$, which specifies that the proposed deterministic technology as a whole, given by the input vector, explains crop output variability across shifting cultivators is not rejected by the data given our the Cobb-Douglas functional form. The second null hypothesis, $H_0 : \gamma = 0$, which specifies that households are operating on the frontier is rejected both by the SPF1 and SPF2 models at any sensible significance level.[12] The third null hypothesis

[10] γ has a value between zero and one and roughly indicates whether variation in actual output from frontier output between households, mainly arises from differences in management practices rather than random variability. The closer the estimated value of γ to zero it is, the lower the effect of inefficiency on crop variability and therefore the lower the estimation bias when using an average input-output response function.

[11] All five tests have been carried out applying the generalised likelihood-ratio statistic $\Lambda = -2\ln[L(H_0) - L(H_a)]$, with q degrees of freedom, where $L(H_a)$ and $L(H_0)$ are the unrestricted and the restricted likelihood functions, respectively, and q is the difference in number of variables used in the H_a and H_0 model specifications.

Table 3: Generalised Likelihood-ratio tests for parameter of stochastic frontier production models

	SPF1		SPF2	
H_0	Λ^a	C.V.^{b}	Λ^a	C.V.^{b}
[1:] $\beta_k = 0,\ k = 1, ..., 3$	32.54	6.25	17.62	6.25
[2:] $\gamma = 0^c$	2.67	2.70	38.68	24.38
[3:] $\delta_j = 0,\ j = 1, ..., n$	n.a.	n.a.	35.52	19.81
[4:] $\delta_Q = 0$	n.a.	n.a.	3.78	1.64

^{a} : $\Lambda = -2\ln[L(H_0) - L(H_a)]$ has χ^2 distribution.

^{b}: Critical Value (C.V.) is at 10% level

^{c}: Λ follows a mixed χ^2 distribution. The critical values are in Kodde and Palm (1986).

considered in table 3, specifies that the coefficients of the explanatory variables in the TIE model within the SPF2 framework are simultaneously zero, i.e., $H_0 : \delta_{ij} = \delta_Q = 0,\ j = 1...n$ (farm and household specific variables), is strongly rejected. The last null hypothesis in table 3, $H_0 : \delta_Q = 0$, specifies that the coefficients associated with the variable soil quality is zero, and hence, that soil quality do not have a direct impact on efficiency. This hypothesis is strongly rejected and implies the non-neutral SPF is superior to the neutral counterpart. We therefore conclude that soil quality does affect shifting cultivators managerial efficiency levels. It should be noted that the SPF1 and SPF2 models are not nested. Hence, SPF1 is not a special case of SPF2, and no set of restrictions can be defined to permit a test of one specification against the other (Coelli 1996).

Production elasticities and returns to scale: The role of soil quality

It has been shown that we cannot reject that the random component of the inefficiency effects makes a statistically significant contribution in the analysis of agricultural production in the municipality of Hocaba ($H_0 : \gamma = 0$ is rejected). I now turn to ascertain the mean production elasticities of the inputs involved in the superior stochastic frontier production models. The calculation of the mean production elasticities concerning the non neutral SPF is not straightforward.

The β_k, $k = 1..3$ parameter estimates in the last column of table 2 refer to the *'frontier'* or *'best practice elasticities'* and are not necessarily the same as the mean output elasticities. They would be if the model was not 'non-neutral' (e.g., SPF2). Note that the estimation of the mean output

[12]The test for absence of inefficiency effects in the SPF2, i.e., $H_0 : \gamma = 0 = \delta_i = 0,\ i = 1...n$,, follows a *mixed* χ^2 distribution (Coelli and Battese 1996). The appropriate critical values for the test are obtained from Table I in Koddle and Palm (1986). If $H_0 : \gamma = 0$ is true, then there are n other δ-parameters which are not present. Hence, the degrees of freedom are for the appropriate critical value in Table I of Kodde and Palm (1986) is $n + 2$, where n is the number of parameters that are specified to be zero but that are not boundary values.

elasticity estimates of soil quality (Q) should be involved because it is also a variable in the TIE model. Thus an estimate of the *elasticity of the TE* given its role in the TIE model is required first. This efficiency elasticity can be predicted using the following expression proposed by (Battese and Broca 1997):

$$\Omega = -\mathcal{C}\frac{\partial \mu}{\partial \ln x_j} \tag{6}$$

where, Ω_i is the elasticity of inefficiency of the x_jth input that enters the TIE model, and C_i stands for the following expression:

$$\mathcal{C}_i = 1 - \frac{1}{\sigma_u}\left\{\frac{\phi\left(\frac{\mu_i}{\sigma_u} - \sigma_u\right)}{\Phi\left(\frac{\mu_i}{\sigma_u} - \sigma_u\right)} - \frac{\phi\left(\frac{\mu_i}{\sigma_u}\right)}{\Phi\left(\frac{\mu_i}{\sigma_u}\right)}\right\} \tag{7}$$

and ϕ and Φ represent the density and distribution functions of the standard normal random variable, respectively. Given the mean of $u_i = 0.29$ and $\sigma_u = 0.35$, $\mathcal{C}_i$ equals 0.53. It follows that the efficiency elasticity of soil quality is equal to $(\rho)(-\mathcal{C}) = (-0.73)$. Referring back to equation (6), the final mean output elasticity of soil quality (Q) becomes equal to 0.19.

The results from the SPF indicates that soil quality has a double role in traditional shifting cultivation in the region. On the one hand, it is suggested that soil quality can significatively increase maize output under an efficient management of the agroforestry system (i.e., an additional 1% soil fertility would imply a 0.91% increase in output). But there is also a negative effect on efficiency of raising soil quality. Thus when the non-neutral stochastic frontier production model is compared with the SPF1 model the soil quality mean output elasticity reduces significatively from 0.56 to 0.19.

The finding that lower soil quality levels are associated with higher TE suggests that shifting cultivators might try to overcome the ecological restriction of cropping in more degraded soils by being more managerially efficient.[13] The result that lower soil quality is associated with higher levels of TE is in line with the neutral-SPF analysis by Sherlund et al. (1998) who found that for a sample of rice farmers in the Ivory Coast, lower fertility of the soil (characterised by a categorical variable reflecting peasants' opinion on the quality of soil) was positively affecting efficiency (and in an statistically significant way). But our result contrasts with Wadud and White (2000) who found that rice farmers in Bangladesh, were more technically efficient with higher soil quality levels (again a categorical variable reflecting farmers' view on the fertility of the soil was used).

Regarding new cleared land and cropping labour, the former shows an elasticity between 0.98 (SPF1) and 1.02 (SPF2). This indicates that farmers are almost operating in an irrational zone

[13] A close inspection of the data shows that there is not a marked difference in the intensity of different labour-specific application on farm according to different land quality user households. Thus, it is hypothesised that it is the quality and not the quantity of the work per unit of farm land what is different across differing land quality users.

of production (increasing returns to land). This is perhaps not surprising, given that shifting cultivation is a pure extensive system where more land means more maize. As far as cropping labour is concerned, the SPF1 model shows an elasticity of 0.25. But when household specific socio-economic characteristics are controlled for (in SPF2), then it appears that cropping labour is being overused (i.e., the elasticity estimate is statistically not different from zero).[14]

As regards the returns to scale hypothesis, the coefficient estimates of the C-D frontier function, suggest that households face increasing returns to scale (1.3 for SPF2). This finding departs from a survey on farm production from various Latin American countries described by López and Valdés (2000) and point out that recent studies have found returns to scale in the range of 0.7 and 0.9.

The level of technical efficiency in shifting cultivation

The average technical efficiency index given in equation (3) is lower when household characteristics are taken into account. The difference is notable: The TE index under SPF1 approach is 0.57 and 0.75 under the SPF2 model. If the efficiency index is translated into inefficiency terms, on average, it would have been possible to increase maize production by up to 33% ($\exp(u) - 1 = 0.33$). That is to say from the realised 0.63 tons to 0.84 tons.[15] Even though pure inefficiency scores are lower than if no socio-economic characteristics are accounted for in the SPF, the predicted TI scores still differ substantially among the sampled households, They range from 0.04 to 4.32.[16]

To give a better indication of the distribution of technical efficiency, a frequency distribution of the predicted efficiencies is plotted in figure 1 a which shows that there is a wide distribution of efficiencies among households involved, and appears to be considerable room for affecting improvements in the technical efficiencies of shifting cultivators in the region.

Relationship of technical inefficiency and household/farm characteristics

Economic efficiency tests only evaluate actual productivity relative to potential productivity and do not imply irrationality on the part of farmers who are inefficient (Llewelyn and Williams 1996).

[14]One cannot, however, conclude by this analysis that cropping labour has no influence on crop production. A more likely explanation is that the vector of inefficiency variables which has been proved to affect the variability in crop production is correlated with farm labour applied to cropping activities, and thus multicollinearity might be the cause for the high standard error of δ_2 within the SPF2 model (Pearson's correlation index between total cropping labour by the household and off-farm labour by the HoH and RoH are significatively correlated at the 5% and 1% significance level respectively).

[15]The average inefficiency index is given by expression: $\theta^S = \sum_{i=1}^{N}[\exp(u_i) - 1]/N$, where $u_i \simeq \mu_i$.

[16]The reported descriptive statistics are those with HH 14 taken out since it produced less than 40 kg. of maize which distorted the average efficiency score.

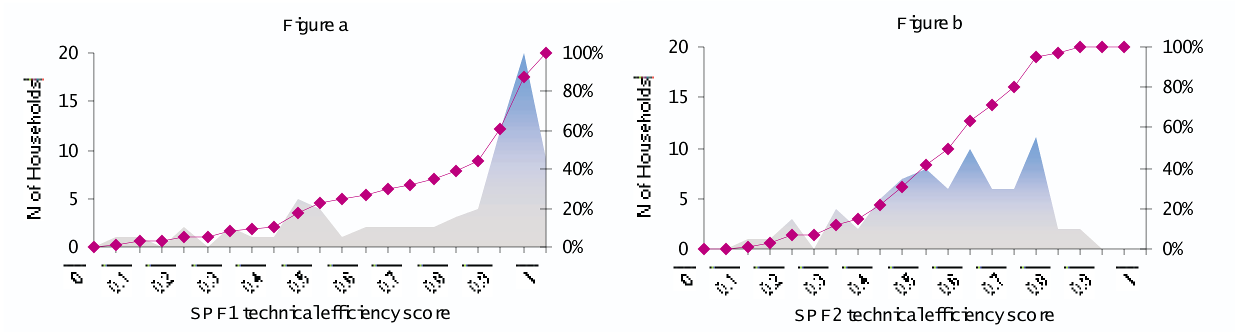

Figure 1: TE frequencies

In fact, farmers' failure to use the most efficient techniques might well be due to nonphysical inputs such as information and supervision that influence the ability of the shifting cultivator to use the actual technology efficiently. However, we do not have this information and therefore we approximate it by household specific socio-economic, demographic and farm characteristics that are likely to affect managerial ability in farming.

Most empirical applications that employ a SPF for estimating the factors of TI in agriculture, employ a two-stage OLS estimation procedure (see: Tadesse and Krishnamoorthy 1997; Abdulai and Huffman 2000; Wadud and White 2000; Bakhshoodeh and Thomson 2001). The two-stage procedure consists of regressing the predicted inefficiency effects obtained from the estimated stochastic frontier, upon a vector of household specific factors. This approach, however has been recently criticised in that, it contradicts the theoretical construct of the frontier model. The problem is that in the first stage, in order to use the Jondrow et al. (1982) approach, u_is were assumed to be independently and identically distributed; however, in the second stage, the predicted inefficiency effects are assumed to be a function of a number of household and farm -specific factors, which implies that they are *not identically* distributed.

Hence, we have followed the method developed by Battese and Coelli (1995). This consists of a single-stage maximum likelihood model in which the one side random error, u_i, from model (5b) is replaced by a linear function of covariates reflecting farm specific characteristics (recall equation (5d)).[17]

[17] Estimations have been carried out using FRONTIER 4.1, an econometric software package designed by Tim Coelli (1996) to provide maximum likelihood estimates of a variety of stochastic frontiers. FRONTIER follows a three-step maximum likelihood estimation procedure. First, Ordinary Least Squares (OLS) estimates of the production function are obtained as starting values. Next, a two-phase grid search' is conducted to refine the starting values. Final estimates are obtained iteratively using the Davidson, Fletcher, and Powell Quasi-Newton Method. The log-likelihood function to be maximised is presented in the appendix to Battese and Coelli (1995).

Most studies have focused on socio-demographic variables such as formal education, age, gender composition. Besides incorporating these variables in our model, we are interested in ascertaining the effect of off-farm labour allocation and poverty levels on TE. Furthermore, we are most interested in knowing which is the effect of the level of natural capital (soil quality) on technical efficiency. Does higher soil quality improve TE? or is there an inverse relationship between soil quality and managerial ability? The expected results are outlined next:

Schooling as a proxy for formal education is expected to have a negative effect upon the inefficiency effects. That is, it is expected that more years of formal education will be associated with smaller values for the inefficiency effects. However, managerial ability in traditional agricultural systems where ecological knowledge and experience are of paramount importance, can be a poor indicator of potential TE. I believe that the *age* of the farmers can be a better indicator of farming experience. Older farmers are likely to have more farming experience and hence be more TE than younger farmers. However, given the strenuous tasks involved in shifting cultivation (e.g., clearing trees), it could also be expected that younger farmers would accomplish most farming tasks in a more technically efficient way.

Given the physical effort required in shifting cultivation, it is also expected for *gender* to have some effect on TE. For instance, if the proportion on active members in the household are predominantly females, it could be expected that efficiency would be lower (in a shifting cultivation context).

The impact of *land tenure* on the TI is in principle dubious, and including a categorical variable indicating whether the land which is being farmed is titled or belongs to the ejido can be used to test the hypothesis that common property land is associated with higher managerial inefficiency by the farmers.

As several authors such as Reardon and Berdegué (1999) and Reardon et al., (2001) are recently stressing, a distinguishing feature of rural households is that they are 'multiactive' given that their multiplicity of income sources (even across individuals in a given family). Rural household members are driven to seek off-farm employment to smooth interyear and intrayear variations in incomes, and to alleviate poverty. These owe much to risky farming, land constraints (ecological constraints), missing insurance and credit markets. The effect of *off-farm employment* by household members upon TE in farming is dubious and has been little studied. On the one hand, farmers engaged in off-farm employment might tend to exhibit lower levels of TE because they might be forced to reallocate time away from important agricultural tasks determined by exogenous non idiosyncratic events (such as rainfall, damage to the crop by birds, and other animals, etc.). On the other hand off-farm employment can create the opportunity to adopt new technologies (e.g., better herbicides sold out of the community). The first negative impact is expected to outweigh the second one given the low levels of use of artificial capital and the need to gather technical information to enhance production efficiency which is mainly based on traditional practices and knowledge.[18]

In addition, *poverty* might also affect TE due to different reasons. If poverty is related to nutrition status, according to efficiency-wage theories, it can be expected that higher poverty (thus lower nutritional status) to be associated with lower TE scores. However the poor can be associated with a more reliance in farm activities compared to non-farm activities, which can serve to build up farming experience (e.g., better ecological knowledge of the functioning of system, etc), thus possibly linking low income levels with higher TE.

Last but not least, *soil quality* might have both positive and negative effect on TE. On the one hand it can be argued that higher soil quality might help ease the problem of cropping in a lower fertility land (presumably with lower weed species population), and thus allow cropping effort on the 'quality' of the labour to be applied in farming (e.g., sowing). Also, lower soil quality is usually associated with more thorny forest bush-tree vegetation which can create problems when clearing the forest land and thus leaving non desired stumps on the ground. On the other hand, lower soil quality can also be seen as a spur factor pushing technical efficiency, by applying labour more intensively in the different tasks in order to overcome the ecological constraint in crop production.

It is interesting to be able to discriminate the above farm and socio-economic characteristics between the head of the household (HoH) and the rest of adult members (aged 16-65) of the households (RoH). This is because although the RoH might engage in crop production, the primary role in shifting cultivation is often taken by the HoH. Hence, *age*, *education* and *off-farm employment* is controlled for both the HoH and an average household 'agent' that refers to the RoH.

In the empirical model equation (5d) is reformulated as follows:

$$\begin{aligned}\mu_i =& \rho_0 + \delta_1(AGEHoH) + \delta_2\ \ln(AGERoH) + \delta_3\ \ln(EDUHoH) + \delta_4\ \ln(EDURoH) + \\ & \delta_5\ \ln(PMENRoH) + \delta_6\ \ln(OFLHoH) + \delta_7\ \ln(OFLRoH) + \delta_8\ DUSUPHoH + \\ & \delta_9\ DUSUPRoH + \delta_{10}\ DLOC + \delta_{11}\ QPRIVATE + \delta_{12}\ POVR1 + \delta_{13}\ln(SQI)\end{aligned} \tag{8a}$$

The result of calibrating the model (8a) using a Maximum Likelihood estimation method is the following one:[19,20]

[18]In order not to bias parameter estimates associated with total off-farm labour supply, two different labour allocation variables: One tells whether farmers there is any engagement in the off-farm labour market (through a dummy variable), and the other with the extent of that engagement in terms of total hours supplied.

[19]Observations: 74 households. $*$, $**$ and $***$ are for significance level at 10%, 5% and 1%, respectively. T-ratios in parentheses. The null hypothesis that all non-intercept parameters in the TIE model are zero is rejected at the 10% significance level according to the likelihood ratio test (see table 3).

[20]The Battese and Coelli (1995) approach handles the simultaneity problem between the SPF and the TIE model.

$$
\begin{aligned}
\mu_i = & \underset{(0.49)}{1.58} - \underset{(2.35)}{1.84^{**}} \ln(AGEHoH) + \underset{(2.40)}{0.67^{**}} \ln(AGERoH) - \underset{(0.90)}{0.51} \ln(EDUHoH) - \\
& \underset{(1.38)}{0.51} \ln(EDURoH) + \underset{(2.44)}{1.52^{**}} \ln(PMENRoH) + \underset{(2.57)}{0.36^{**}} \ln(OFLHoH) - \\
& \underset{(3.44)}{0.57^{***}} \ln(OFLRoH) - \underset{(1.46)}{1.71} \ DUSUPHoH + \underset{(4.46)}{4.82^{***}} \ DUSUPRoH + \\
& \underset{(2.51)}{1.02^{**}} \ DLOC + \underset{(1.35)}{0.68} \ QPRIVATE + \underset{(1.70)}{0.82^{*}} \ POVR1 + \underset{(1.89)}{1.37^{*}} \ln(SQI)
\end{aligned} \tag{8b}
$$

We now turn to interpret the econometric results.

Household's age:

There seems to be a statistically negative effect of head's age ($AGEHoH$) on inefficiency levels. This conforms with results obtained by Abdulai and Huffman (2000) for smallholders in Ghana and Battese and Broca (1997) for wheat farmers in Pakistan. However it differs from the results by Seyoum et al. (1998) regarding maize farmers in eastern Ethiopia. The result suggests that older HoHs, gain in efficiency through higher farming experience (e.g., ecological knowledge of the SC system) which outweighs the effect of having lower capability due to aging of undertaking straining tasks.

The estimated δ coefficients cannot be directly interpreted because it represents the effect on μ instead of efficiency. We therefore follow Battese and Broca (1997) to derive the *efficiency elasticity* as outlined in equations (6 - 7). The calibrated parameters from equation (8b) can be interpreted as the elasticity of the efficiency index $[\exp(-u)]$ when δ_i is scaled by $[-\mathcal{C} = -0.53]$. The final efficiency elasticity of $AGEHoH$ equals to $-\mathcal{C}\delta_1 = 0.97$. Hence, a 1% increase in $AGEHoH$ increases the efficiency score by almost the same percentage. It has been suggested by Coelli that marginal effect can be obtained by multiplying the coefficient by the ratio of the means.[21] The marginal effect is equal to 0.014 (i.e., $\partial \exp(-u)/\partial[AGEHoH]$).

On the contrary, the RoH's average age $AGERoH$ positively affects inefficiency in shifting cultivation. Following the above methodology, the SPF shows a TE elasticity for $AGERoH$ of -0.35 and at the sample means, a marginal effect on TE equal to -0.008.

Formal education of the household:

Formal education, proxied by schooling years, appears not to affect efficiency strongly given the relatively high standard errors of δ_3 and δ_4. However, their negative signs indicate that HoH's and

However, unfortunately this method cannot handle potential heteroscedasticity problems. In order to minimise potential heteroscedasticity, the regressors have been transformed into their natural logarithms. Thus, a log-linear TIE model has been applied.

[21] Personal communication, May 2001.

RoH's formal education (*EDUHoH*) might increase efficiency levels. This likely result is in line with most empirical studies linking peasants' human capital and TE (Abdulai and Huffman 2000, Ali and Flinn 1987, Coelli and Battese (1996), Sherlund et al. 1998, Wang et al. 1996).

Effect of gender composition:

Concerning the gender composition of adults in the household, it appears to be a positive effect of the proportion of active males (*PMENRoH*) on inefficiency. This is supported by the statistically significant coefficient δ_5.

The positive sign indicates that a higher proportion of males (adults) might be associated with lower TE (with a TE estimate around -0.8). The marginal effect on the technical inefficiency score in this case is -0.009 for each 1% increase in the ratio of adult men to total adults in the family. The result contrast with the one by Mochebelele and Winter-Nelson (2000), who have found no effect of gender composition on cereal production efficiency in Lesotho.

Effect of land tenure:

Concerning land tenure, it does not appears to be any empirical evidence pointing towards a difference in TE levels between private land owners and ejido users. This is due to the low significance level associated with the coefficient for the dummy variable *QPRIVATE*. This result should not be interpreted as generally refuting the expectation that well established property rights positively affect the level of entrepreneur management and the quality of labour force. The land under the *ejido* system has a long standing community-level recognition of ownership as the privately owned land might posses.[22]

Our results are in accordance with that of Kalijaran (in Bravo-Ureta 1993) who could not find any empirical evidence regarding the effect of land tenure on farmers' technical efficiency. In a recent study, Otsuki and Reis (1999) have suggested (within a more regional context) that in the Brazilian Amazon the density of titled land (including communally owned land) in the counties were associated with higher efficiency in crop production.

Effect of off-farm employment: The focus here is on the effect of off-farm labour allocation on farm TE levels. This hypothesis has recently been tested by Abdulai and Huffman (2000) in Northern

[22] Interestingly, a closer look at the data, appears to indicate that land owners in the sample apply around 20% less labour in clearing per unit of forest land than ejido users while they apply 6% more of their farming time in clearing forest land. In addition, weeding is more thoroughly carried out by ejido users (they apply 31% more hours per unit of land in weeding). It also appears that while only 14% of ejido user households have some cattle, all private property land owners possess cattle. This information might indicate that private land owners might direct some of their shifting cultivation time to cattle raising. In addition, it is customary to feed the cattle with maize stalks once it has been harvested, and thus is not left mulching to enhance the soil's organic matter.

Ghana and Mochebelele and Winter-Nelson (2000) in Lesotho. Both investigations reached opposite conclusions. While off-farm labour supply by farmers in Ghana was curtailing farm efficiency, increased migrant labour from Lesotho to South Africa increased farm efficiency by the migrant farm households. Mishra and Goodwin (1998), although not focusing on TE, have tested whether higher returns in farm production affects off-farm labour allocation decisions by agricultural households in the state of North Carolina (USA). Their result could not reject the existence of a negative effect between higher returns and off-farm labour supply.[23]

As regards off-farm employment, the model attests that there is no (or eventually negative) effect of HoH's participation in the off-farm labour market (*DUSUPHoH*), and that there is a positive effect on inefficiency of RoH's participation *DUSUPRoH*. The results suggest that when the RoH engages in the off-farm labour market, inefficiency increases significatively. [24]

The off-farm labour supply hours (and not just the decision to participate) has the opposite effect compared to off-farm labour participation decisions. The empirical model suggests that the efficiency elasticity of HoH's off-farm labour supply (*HOFFHoH*) is -0.19 (marginal effect on efficiency of is -0.02 for each 100 hours supplied off-farm), the RoH's average off-farm labour supply is associated with a positive TE elasticity: 0.30 (the marginal effect being 0.03 for each 100 off-farm hours supply).

These results indicate, in line with the findings by Abdulai and Huffman (2000) for northern Ghana, on the one hand off-farm labour supply by primary shifting cultivators (HoHs) is restricting farm production and decision making activities in a statistically significant way, thereby worsening TE. On the other hand, in line with the findings with Mochebelele and Winter-Nelson (2000) whereby off-farm migrant labour was associated with higher efficiency, here we also observe that the positive effect of RoH's off-farm labour supply on efficiency indicates that off-farm work by non heads, and therefore the income they generate more than compensates for the constraints to TE caused by reduced household labour availability. This finding points towards the possibility that households with more finance through higher engagement by the RoH in off-farm income generating activities can be highly responsive to farm management needs. It is therefore important to see whether income poverty is an structural factor reducing farm efficiency in Yucatán. This is tested by focusing on the sign of the poverty dummy.

[23]Instead of TE, Mishra and Goodwin (1998) used an index of farming performance using the ratio of the average total farm receipts to the average farm production expenses.

[24]The *DUSUPHoH* and *DUSUPRoH* dummy variables have been included to control for the high variability in participation by HoHs and RoHs which can bias the effect of actual off-farm labour supply by the household members on efficiency.

Effect of poverty:

Poverty (*POVR1*) seems to have a positive effect on inefficiency according to the statistically significant (at 10% level) and positive sign of the coefficient $\delta_1 2$. The obtained result is somewhat in line with Wang et al. (1996) who found that Chinese farmers are less 'profit efficient' when their income falls. Moreover, the negative effect of poverty on TE is complemented with the positive effect on TE of off-farm employment by the RoH.

There is a long standing research that links poverty- undernourishment and farm productivity in rural areas of developing countries.[25] This effect might lose signification in our study given that for a sample of 20 households, there is no evidence linking nutritional status of children below 5 years old and the income poverty status in our sample. Given that it is sensible to think that children might be at least as susceptible as adults to undernourishment when poverty is prevalent, the linkage between poverty and undernourishment is at the least not clear enough to consider the poverty-efficiency hypothesis to be related through the undernourishment effect.

It can be thought that given off-farm labour supply is already controlled in the model, it is likely that the negative correlation between poverty and TE might be due to the diversification of the labour portofolio not just towards the off-farm market sector but also to other natural resource based activities such as fuelwood collection and henequen cultivation. In addition, it might well be the case that the higher reliance by the poorest on the joint production of intercropped vegetables might curtail some TE in maize production. This is an hypothesis which unfortunately cannot be tested due to lack of data on the output of crops such as beans and squash.

6 Concluding remarks

There are various salient results from the TE analysis. One is that there seems to be significant room for increasing crop output in Yucatán, without any need to clear additional units of forest land. It has been estimated that maize output could be increased by up to 33% if labour and forest biomass (through soil quality) were used more efficiently. This means that policies aiming at increasing TE levels of traditional shifting cultivating farmers can result in a win-win strategy. Labour could be saved under current yield levels, which could then be supplied to the off-farm sector. Most likely this would help households in increasing their low income levels. In addition,

[25]See Dasgupta (1993, 1997) and Deolalikar (1988) for a conceptual discussion and review of the link between poverty, undernourishment and the level of 'productive' labour effort in traditional farming systems of developing countries. See Sahn and Alderman (1988) for an empirical application for testing the effect of caloric intake and the productivity of labour in developing countries.

soil conservation could be achieved without compromising the current generation's crop yields. Further, besides the long term beneficial effects of conserving the soil today, there are imminent short term gains from investing in soil conservation through increases in efficiency. The frontier production analysis indicates that soil quality elasticity is relatively high lying between the elasticity of forest area cleared and that of labour used in cropping.

Another interesting result is that soil quality directly affects TE. The hypothesis that higher soil quality would enhance efficiency in production of staple food has been rejected for the case of a representative municipality of the Yucatán. This was an unexpected finding. The data suggests that peasant households using lower quality land do better in efficiency terms, than those households using higher quality land. Thus, there is an indication that the response by peasant households to the ecological constraint is to substitute lower soil quality for higher managerial ability. In other words, soil quality is considered to be a scarce resource by shifting cultivating households. This is corroborated by the fact that even after controlling for the increase in efficiency due to using lower quality land, the elasticity of production of soil quality is positive.

By controlling for various household demographic variables, the question of whether and how off-farm labour supply affects TE in production has been uncovered. While more off-farm hours supply by the head of the household reduces cropping efficiency, the opposite is the case as regards other members of the household. Thus instead of focusing on farm households as homogeneous entities, the importance of analysing intrahousehold labour allocation decisions needs to be stressed.

What is often perceived as a direct link between poverty and environmental degradation, proves under careful analysis to be a complex interrelationship between a household's level of welfare and wealth and its economic behaviour, such as the allocation of labour and other assets. This paper has found that poverty is negatively correlated with TE. Thus, one reason for the poor being associated with higher rates of resource degradation might be due to the over-use (in a TE sense) of the natural resource base. This problem is somewhat made worse given that the poor might be oversupplying on-farm labour (from a TE perspective) and not being able to free labour time that could be used to generate additional income (for instance by supplying more off-farm labour at prevailing market wage rates).

A possible limitation of the present analysis is concerned with the nature of the data set given that it is cross sectional. The data can describe the technology used and the efficiency level associated with an specific agricultural cycle. This certainly impedes analysing multi-season efficiency which can be linked to risk averting strategies (Coelli 1995), and measuring any productivity growth rates which is made up of changes in TE plus shifts in the frontier (Grosskopf 1993). A possibly fruitful extension for analysing the effect of soil quality in the level of technical efficiency in small-scale agriculture in the developing could be the use of panel data.[26]

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[26] A panel data methodology would have the additional advantage and that the one-sided error is not forced to follow a specific distribution by making it possible to have testable propositions (Bravo-Ureta et al. 2000, Bauer 1990). In addition, the meta-analysis of technical efficiency by Bravo-Ureta et al. (2000) points out towards the possibility that cross sectional data might be associated with a downward bias in the TE score levels than when panel data is used.

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