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THE ADOPTION OF SOIL CONSERVATION TECHNOLOGIES BY SMALLHOLDER FARMERS IN MALAWI: A SELECTIVE TOBIT ANALYSIS

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Abstract

A selective tobit model was used in this study to analyse factors that influence the incidence and the extent of the adoption of soil conservation technologies by smallholder farmers in Malawi. The study results indicate that factors that influence farmers' decisions to adopt soil conservation technologies may not necessarily be the same factors that influence the subsequent decision on levels of adoption. Farmers' knowledge of the effects of soil erosion, age of the household head and farm labour availability were found to be the main factors influencing the adoption of soil conservation technologies by smallholder farmers, while factors that usually affect profitability at farm level such as output level, labour and land size were the main influencing factors on the extent of adoption. The implication of these results is that different policy prescriptions on soil conservation should be guided by the goals the government wants to achieve. For example, the government may want to persuade more farmers to participate in soil conservation or alternatively, to encourage farmers already using the technology to intensify their involvement.

1. INTRODUCTION

Increasing pressure on agricultural land in most Sub-Saharan Africa (SSA) has resulted in high nutrition loss and of the breakdown of many traditional soil conserving and fertility enhancing measures. Rapid population growth is a major source of pressure on agricultural land in Malawi, as almost 85% of the population earns their livelihood from agriculture. Population pressure has been absorbed either by splitting further the already small pieces of land or by extending cultivation to marginal areas. According to the FAO (1998), about 55% of farming families in Malawi had less than one hectare of land. This figure had risen to 76%, by 1997, with about 41% cultivating less than half a hectare. It is inevitable that such a rapid decrease in land holding per family has seriously reduced smallholder farmers' ability to rest part of their land (fallow) as an option to rebuild soil fertility.

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Most countries in SSA have been experiencing declining per capita food production since the 1980s (FAO, 1991). Declining food production in the region is mainly attributed to shrinking of the natural resource base (e.g., soil fertility) and unless this resource base is enhanced, it will be difficult to reverse the situation (Stoorvogel & Smaling, 1990). The problem of declining soil fertility is acute in Malawi, a country with one of the highest rates of soil erosion in SSA (Bojo, 1996). The consequences of declining soil fertility are severe especially among smallholder farmers who do not apply or only apply inadequate levels of external inputs such as fertiliser. Smallholder farmers in Malawi account for almost two-thirds (1.98 million hectares) of the total harvested area in the country, hence this problem poses a national crisis. Another important factor to consider, especially when evaluating options to counteract the problem of declining soil fertility and productivity in Malawi, is the poverty situation among smallholder farmers. Poverty has worsened in recent years with about 70% of farm families in Malawi classified as poor (FAO, 1998). The growing number of poor households means that only a few farm families can now afford to purchase the necessary external inputs such as inorganic fertilisers. A typical smallholder farmer in Malawi has only limited options to counteract the problem of declining soil fertility. Soil conservation is thought to be among the most reliable and affordable technologies that smallholder farmers can utilise to reduce or reverse declining fertility.

However, soil conservation technologies are not readily adopted in Malawi (Mangisoni, 1999). This dilemma needs to be overcome if efforts to utilise soil conservation technologies in order to reduce soil erosion and declining fertility are to be successful. Smallholder farmers would adopt soil conservation technologies as long as they are profitable (Pagiola, 1993). Returns to smallholder farming in Malawi have generally been low and therefore, have discouraged farmers from investing in soil fertility enhancing technologies (FAO, 1998). In other words, lack of proper incentives is one of the key explanations for the low adoption of soil conservation technologies in Malawi.

Quite often, farmers will try a technology when it is first introduced, i.e. in the project phase, only to drop out when it is time for them to stand alone without the donor or government support. Such farmers frequently make a rational economic decision after weighing the costs and benefits accruing from the continued involvement with the technology. It is important to realise that the adoption of innovations in general is not a once-off decision as many studies have assumed. Rather, it is a stepwise decision made after carefully weighing opportunity costs at each point (Goetz, 1992; Byerlee & Hesse de Polanco, 1986). Understandably, smallholder farmers always want to avoid unnecessary risks and will, therefore, abandon a technology once their perceived benefits diminish significantly or do not seem to offset the costs involved. So far, adoption studies in Malawi have not separated factors that influence farmers to adopt a technology and factors that influence their subsequent decision to intensify levels of use. This study is, therefore, intended to contribute towards a better understanding of the sequence of decisions faced by a farmer in adopting soil conservation technologies and the important factors that influence these decisions.

The following section briefly reviews the history and status of soil conservation in Malawi. Section 3 presents the approach and methods used in the empirical analysis. The empirical model is specified in section 4. Section 5 presents the empirical results. Section 6 draws the conclusions and implications of the study.

2. SOIL CONSERVATION TECHNOLOGIES IN MALAWI

Soil conservation in Malawi has a long history dating back to the colonial period. In the colonial period, before 1964, soil conservation was characterized by coercive methods to force farmers to adopt alien resource conservation technologies, which were principally European or British-oriented (Mangisoni, 1999). In the early 1980s, the country witnessed the emergence of biological and small-scale physical conservation techniques that were thought to be better suited to smallholder farmers. In spite of all the efforts to persuade smallholder farmers to conserve their over-cultivated lands, traditional cultivation practices are still being witnessed in most parts of the country and erosion continues to limit productivity of most soils.

Many technology adoption studies have been carried out in developing countries (Feder *et al,* 1985; Heisey & Mwangi, 1993; Hassan *et al*, 1998; Alene *et al*, 2000). However, the importance of factors affecting technology adoption differs across countries and regions due to differences in natural resources, cultural and political ideologies and socio-economic factors. One of the most recent and notable studies on adoption of soil conservation technologies in Malawi is the one conducted by Mangisoni (1999) who reported generally low levels of adoption. More research is required in order to understand the reasons behind the low adoption so that appropriate policy interventions can be formulated. Such efforts are necessary because soil conservation has been identified as one of the most reliable and affordable techniques for smallholder farmers in the fight against declining soil fertility in the country.

Most studies carried out in Malawi on adoption were based on the assumption that farmers make one decision combining both the incidence and extent of adoption. This study, however, models farmers' adoption decision as a two- step process. The first step is the decision whether or not to adopt the technology. The second step is to decide on how much of the technology to use (level of use). A selective tobit model is used due to its ability to simulate the two-step farmer decision-making process. The soil conservation technology considered in this adoption study was the small-scale physical technique called marker ridging. Apart from acting as the first line of defence, the marker ridge is used as a benchmark for the alignment of all other ridges in the farmer's plots across the slope.

3. APPROACH AND METHODS OF THE STUDY

When data are censored, the distribution that applies to the sample data is a mixture of discrete and continuous distribution (Green, 2000). Adoption studies usually present a scenario where only part of the population participates in a particular technology. In most cases non-participants face thresholds that can only be surmounted at a cost exceeding the net benefit realized by participating in the technology (Goezt, 1992). Farmers are usually faced with a two-step decision process. Firstly, farmers decide whether or not to adopt a technology and then decide on their level of involvement or extent of adoption.

The regression model commonly employed in the analyses of adoption decisions is based on a tobit model applied to censored data. Unfortunately, ordinary least squares estimation of the model yields biased and inconsistent parameter estimates. James Heckman (1979) proposed a two-stage estimation process that yields consistent parameter estimates. However, the two-stage estimator involves heteroscedastic errors so that the usual t tests are biased. The maximum likelihood estimator is, therefore, found to be the most efficient estimator (Pindyk & Rubinfeld, 1998).

Admittedly, the tobit model is rather restrictive in the sense that a positive (negative) parameter increases (decreases) both the probability of an individual participating in a technology as well as the level of involvement/adoption. As such, the tobit model may not be the most appropriate in cases where farmer’s decision to adopt or try a technology is influenced by different sets of variables from those that influence the farmer’s decision on the level or extent of adoption (Goetz, 1992). A selective tobit model is, therefore, used in this study. This model simulates closely the decision maker's problem: Firstly, whether or not to adopt a technology, and secondly, if adopted, what level of adoption? In such cases, different policy prescriptions will have to be made depending on whether the government aims to increase the number of farmers participating in soil conservation technologies or persuade those farmers already participating to intensify their involvement. For example farmers may expand their use of the technology by allocating more land to soil conservation or by increasing labour use etc.

4. SPECIFICATION OF THE EMPIRICAL MODEL

This study uses a selective tobit model employing the maximum likelihood method. Sample selection models (Greene, 1998) share the following structure: A specified model (equation 1) applies to the underlying data, which are, however, not sampled randomly from this population. Data describing this relationship are observed only when the response variable *Z** crosses a threshold (i.e., equal to or greater than 1). The general solution to the selectivity problem relies upon an auxiliary model of the process generating the unobserved response variable Z*. Information about this process is incorporated in the estimation of:

$$\mathrm{Y} = \beta^{'} X + \varepsilon \tag{1}$$

Where *X* is the vector of independent variables. We assume that the non-random (systematic) process that switches households into soil conservation adoption state, is given by equation 2a

$$z_i = \alpha^{'} v + \upsilon_i > 0 \qquad \upsilon_i \sim \mathrm{N}(0, \sigma_\upsilon) \tag{2a}$$

$$z_i = 0, otherwise \tag{2b}$$

The sample rule is that z_i and X_i are observed only when Z_i^* is greater than zero and note that Y is censored at 0.

The probability that farmer *i* participates in soil conservation (the response variable Z) depends on a set of explanatory variables X

$$\Pr\mathrm{ob}(\mathrm{z_i} = 1) = \Phi(\mathrm{X_i}\beta / \sigma) \tag{3}$$

for those with $z_i = \mathrm{X}^{'}\beta + \upsilon > 0$ or when $\mathrm{z_i} > 0 \Rightarrow \mathrm{X}^{'}\beta > -\upsilon_\mathrm{i}$

$z_i = 0, otherwise$

Here, σ is the standard deviation and Φ(.) is the standard normal distribution function of the error term υ in equation (2a).

The tobit model with sample selection uses the linear prediction of the underlying latent variable

$$E\,[Y^*|z=1] = \beta'X + \rho\sigma\lambda \qquad (4)$$
$$\lambda = \phi\,(\alpha'Z)/\Phi(\alpha'Z) = \phi/\Phi$$

where λ is Mill's ratio or hazard function, displayed and kept for MLE in LIMDEP (Green, 1998) and $\phi = \partial\Phi(X^{'}\beta)/\partial X^{'}\beta$, is the ratio of the marginal to cumulative probability of a household participating in soil conservation.

The term λ_i corrects for the bias associated with omitting households not involved in soil conservation when it is included in an OLS regression of non-zero values (regression restricted only to households involved in soil conservation). The predictions are based on linear, single equation specification and they do not exploit the correlation between the primary equation and the selection model. Further manipulation is therefore required.

The tobit model with selection using truncation in a bivariate normal distribution would be as follows

$$\mathrm{E}[\mathrm{Y}/\mathrm{Y} > 0, \mathrm{z} = 1] = \beta'\mathrm{x} + \mathrm{E}[\varepsilon \mid \varepsilon > -\beta \mid \mathrm{x}, \mathrm{u} > -\alpha'\upsilon] \qquad (5)$$

Simplified as:

$$E[\varepsilon \mid \varepsilon > -\beta' x, u > -\alpha' x] = \sigma E[q \mid q > h, u > k],$$

Where
$$q = \varepsilon/\sigma,$$
$$h = -\beta' x/\sigma,$$
$$k = -\alpha' z$$

Let $\delta = -1/(1-\rho^2)^{1/2}$

Then, $E[q \mid q > h, u > k] = \{\phi(h)\Phi[\delta(k-\rho h)] + \rho\phi(k)\Phi[\delta(h-\rho k)]\}/\Phi_1$

Thus, $$\mathrm{E}[\mathrm{Y} \mid \mathrm{z} = 1 = \Phi_1\beta'\mathrm{x} + \sigma\{\phi(\mathrm{h})\Phi[\delta(\mathrm{k}-\rho\mathrm{h})] + \rho\phi(\mathrm{k})\Phi[\delta(\mathrm{h}-\rho\mathrm{k})]\} \qquad (6)$$

The probit model precedes the selection tobit model in order to provide starting values for the MLE (Heckman procedure). Results of the probit model (equation 3) show which variables determine whether or not a farmer participates in soil conservation. Probit model parameters are used for fitting the sample selection function. However, parameters at this point are still inconsistent since results are obtained by least squares as is the case in any basic tobit model. Parameter estimates are not efficient because the error term is heteroscedastic. Using MLE of the selective tobit model yields consistent and efficient parameters (equation 6). This equation computes variables that influence the farmer's decision on the levels of involvement in using the soil conservation technology.

4.1 Choice of variables

Extra labour employed by the household due to its involvement with the technology of soil conservation was used as the dependent variable (Y) in the selective tobit model. The study found a close link between extra labour required by a household due to its involvement in soil conservation activities and the extent of the household's involvement in the technology. It is believed that interesting results could also be achieved if land allocated to soil conservation was used as the dependent variable in the selective tobit model. However, most farmers could not precisely indicate the size of land they allocated to soil conservation.

The choice of independent variables in the model was based on a number of factors and assumptions. For example, level of schooling of the head of household is assumed to be key to increasing the level of farmer's understanding and therefore, would positively influence adoption of new technologies. Land ownership can positively or negatively influence adoption depending on who owns the land and who makes farm decisions. Age of household head can be positive or negative depending on the position of the household in the life cycle. Younger farmers are more likely to be attracted by new technologies and have more need for extra cash (however, limited cash resources may be a constraint). On the other hand, older farmers may easily be discouraged from adopting new technologies especially if labour demand is high. Family labour availability may positively influence adoption and extent of adoption as it eases the labour constraint faced by most smallholder farmers. Increased yield (output levels) is expected to positively affect the extent of technology adoption. Production assets held by the household tend to reflect the household's wealth position. In most rural households and the more the assets the more likely that the household will adopt the new technology. Erosion taking place in the field can have positive or negative influences on adoption. Frequently, levels of on-going soil erosion in the field force some intervention and, therefore, has a positive influence on adoption of soil conservation technology. However, advanced levels of soil erosion in the field can sometimes force the farmer to abandon the field, especially where land is not scarce. This was experienced in some parts of Nkhata-Bay district.

4.2 Data and data limitations

The alarming levels of land degradation through soil erosion in Malawi has in recent years forced the government to take some counteracting measures to curb or limit this problem. In such vein, the government of Malawi, with support from USAID, embarked on a project in the mid 1990s to monitor soil erosion in some identified districts and also introduced some small-scale soil conservation technologies to smallholder farmers in the study areas. The project was not successful in most of the districts apart from Mangochi and Nkhata-Bay districts in the Southern and Northern Regions respectively. Mangochi and Nkhata-Bay districts were therefore chosen for this study as some soil conservation technology (marker ridging) was introduced to smallholder farmers under the government project and enough time has elapsed since the trial phase of the project was concluded.

The marker ridge technique acts as a line of defence against water runoff, and is also used as a benchmark to align ridges in the field across the slope. Sometimes the marker ridge is reinforced by vetiver grass.

A total sample size of 263 households was surveyed, 120 households from Nkhata-Bay and the remainder from Mangochi district. However, due to the problem of incomplete data for some questionnaires, only 260 households were used in the analysis. Separate regression analyses were run for the two districts considering that farmers in these areas are not exposed to the same influences. A dummy variable for region was significant indicating that data from the two districts could not be pooled.

Underreporting of yield data was the most frequently encountered problem, especially in Mangochi district. This district is among those most affected by drought and floods in the Southern region of Malawi. In the previous two years, residents benefited from government's starter pack program (distribution of free inputs, mainly seed and fertilizer). Some respondents underreported their yield hoping that there would be distribution of free inputs to the poor. Data collection in Mangochi might also have been compromised due to high illiteracy levels in this district. Many respondents could not precisely report land that was allocated to soil conservation. These limitations may have affected the results for this area.

5. EMPIRICAL RESULTS

The results for the probit and selective tobit models (MLE) are presented in Tables 1 and 2 for Nkhatabay and Mangochi districts respectively. The probit model analysed variables that are key determinants of whether or not a farmer will choose to participate in soil conservation (adoption of marker ridging). The selective tobit model, on the other hand, considered key factors influencing farmers' decision on the extent (level) of adoption, conditional on having adopted the technology.

Important factors influencing farmers' decision to adopt soil conservation technology in Nkhatabay district included knowledge of the household head on how soil erosion affects quality of land and productivity, age of household head and land size. All these factors were highly significant at the 10% level. The signs of the estimated parameters were as expected. Farmers' knowledge about the negative effects of soil erosion on soil quality and productivity was found to have a strong influence on adoption even in areas of high illiteracy like Mangochi district. Formal education was key to increased farmers' understanding and therefore an important factor influencing adoption of new technologies. Accordingly, relevant knowledge about the subject matter (e.g. need for soil conservation) has far reaching influence, especially in rural areas where the majority of them have no formal education. This suggests the importance of strengthening farmers' education and extension services in rural areas. Age of the household head positively influenced adoption. However, further increase in age beyond a threshold i.e., above the economically active age category, affects adoption negatively. Marker ridging is labour intensive, especially in the first year, and could therefore be very taxing for farmers of advanced age if they do not hire labour. Land size is another important variable influencing farmers' decision to adopt soil conservation techniques in Nkhatabay district. Land size has a positive influence on adoption of marker ridging techniques i.e., there is a high chance of adoption among farmers owning large pieces of land.

Important factors that influence farmers' decision on the extent of adoption included output level (yield level), labour availability, land size and production assets owned by the household. These were all statistically significant at the 10% level. However, it should be noted that some factors such as land size were influential at both stages of farmer's decisions, i.e. decision to adopt and extent of adoption. What may vary in such cases is the variables' level of influence in particular decision. Hence, computation of marginal effects would provide more detail. When farmers are deciding on the extent of involvement in the technology, key factors are those that affect profitability at farm level, e.g. level of output. This result supports the finding by Pagiola (1993), who indicated that smallholder farmers would invest in soil conservation as long as it is profitable.

In Mangochi district, key factors influencing farmers' decision to adopt marker ridging techniques were mainly knowledge of household head, labour availability (number of adults), level of current soil erosion observed in the field and production assets owned by the household. It should be pointed out that knowledge of household head on issues relating to soil erosion and soil conservation technologies relies heavily on extension work in the area. The extension service is vital to improve farmers' understanding of the subject matter, even in areas of high illiteracy levels. Labour availability was also positively related to adoption. Mangochi is among the districts in Malawi with the highest figures of HIV/AIDS. The number of female-headed households in this district was also high (over 30%). As such, labour availability should be one of the most important factors to consider when deciding on adoption of any new technology especially when such technology is labour intensive.

Farmers' decision on the extent of adoption was highly influenced by output level, labour availability, and production assets owned by the household. Knowledge of the household head on the effects of soil erosion on soil quality and productivity also influenced the extent of adoption. Significance was at 10 % level or lower. The results in Mangochi could have been much better if some of the problems experienced during data collection were avoided. The results for Mangochi district were still as expected except for the sign in the level of the erosion variable.

Reported R-squares were 0.30 and 0.35 for Nkhatabay and Mangochi districts, respectively. R-squared for cross-section studies using censored data (binary dependent models) to explain technology adoption usually have a low explanatory power (Goodwin & Schroeder, 1994; Mitchell & Carson, 1989; Pindyck & Rubinfeld, 1998).

Table 1: Factors influencing incidence and extent of adoption of soil conservation technology by smallholder farmers in Nkhatabay district

Probit Model		
Variables	coefficient	Pvalue
Constant	-4.7375	0.0057*
Land ownership	0.1666	0.9610
Knowledge of hh	1.4695	0.0015*
Number of adult	0.4288	0.7246
Year of schooling	0.7203	0.1528
Age of hh head	0.1648	0.020*
Square age of hh	-0.1926	0.0099*
Land size	0.4408	0.0472*
Yield level	0.6637	0.4746
Level of erosion	0.2179	0.4868
Production assets	0.1267	0.3535
Log likelihood function	-50.36	
R^2	0.30	
Selective Tobit (MLE)		
Constant	-2.5447	0.8163
Land ownership	-	-
Knowledge of hh	8.9712	0.0198*
Number of adult	1.0704	0.1272*
Year of schooling	0.2717	0.3454
Age of hh head	-0.1316	0.7894
Square age of hh	0.5627	0.9176
Land size	2.5826	0.0000*
Yield level	0.1941	0.0180*
Level of erosion	-0.3533	0.8948
Production assets	0.3534	0.4549
Log likelihood function	-313.60	

* = significant at 10% or lower.

Table 2: Factors influencing incidence and extent of adoption of soil conservation technology by smallholder farmers in Mangochi district

Variable	coefficients	P value
Probit Equation		
Const	0.2771	.8092
Land ownership	-0.1391	.6522
Knowledge on erosion	.7429	.0553*
Number of adults (labour)	.1444	.0245*
Age of household head	.2961	.5693
Square age	-0.0013	.8137
Level of erosion	.1074	.0023*
Production assets	.7298	.0215*
Yield level	.2409	.4724
R^2	35	
Log likelihood function	-59.03	
Selective Tobit Equation		
Const	7.8595	.7449
Land ownership	-	-
Knowledge on erosion	2.0059	.0657*
Number of adults	5.0103	.0000*
Age of hh head	1.3493	.1978
Square age	-.9301	.3981
Level of erosion	-.2641	.9633
Production assets	.1054	.0001*
Yield level	.3423	.0000*
Log likelihood function	-646.17	

* = significant at 10% or lower.

6 CONCLUSIONS

Generating the right information is key to the formulation of relevant policies. This study was aimed to contribute to the proper understanding of how smallholder farmers in Malawi make their decisions when adopting soil conservation technologies. A Selective Tobit Model was used to simulate the two-step decision-making process of farmers with respect to adoption and subsequently, the extent of adoption. The results of the empirical analysis revealed that factors that influence farmers' decision to adopt soil conservation technology may not necessarily be the same as those that influence farmers' choice on the extent of adoption or intensity of involvement. Farmers' decision to adopt marker-ridging technology was primarily influenced by knowledge and age of the household head, labour availability and level of erosion currently taking place in the farmers' field. On the other hand, key factors influencing the extent of adoption were mainly those affecting the profitability of the farm, such as output level (yield), land size, labour availability and production assets owned by the household. Some factors such as knowledge of the farmer and labour availability were influential in both levels of decision-making. Computation of marginal effects in such instance would indicate the level of influence of the variable. The implication of these results is that different policy prescriptions on soil conservation should be guided by the goals the government wants to achieve, for example, whether the government wants to persuade more farmers to participate in soil conservation or to encourage farmers already participating in the technology to intensify their involvement.

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