AGREKON

Vol 40 Number/Nommer 3
September 2001

Published by the
Agricultural Economics
Association of South Africa

Gepubliseer deur die
Landbou-ekonomievereniging
van Suid-Afrika

ADOPTION AND INTENSITY OF FERTILISER AND HERBICIDE USE IN THE CENTRAL HIGHLANDS OF ETHIOPIA

L. Dadi[1], M. Burton[2] and A. Ozanne[3]

Tobit and Heckman analysis is used to investigate the factors which influence the adoption and intensity of use of fertiliser and herbicide on smallholder farms growing wheat and tef in the East and West Shewa zones of the central highlands of Ethiopia. Primary data on personal, household and farm characteristics was collected from a random sample of 200 farmers. Results indicate that structural factors - in particular oxen ownership, distance to market and region - are the main determinants of adoption and intensity of use of the technologies rather than personal characteristics - such as age and gender - extension activity or attitudes to price and risk.

1. INTRODUCTION

Like many less developed countries, Ethiopia has difficulty feeding its rapidly growing population and is severely constrained in its ability to import foreign products for domestic consumption and capital goods for the development of the economy. Agriculture is the country's most important economic activity in terms of providing food, income, employment and foreign exchange. However, productivity on smallholder farms, which dominate agricultural production, is low, averaging 11.5 qts[1]/ha for cereals, and this low crop productivity at least partly explains why food availability per capita in Ethiopia is one of the lowest in the world.

In principle, agricultural growth could be achieved by expansion of the cropped area, intensification or both. However, the scope for increasing the area under crops in the central highlands where much of the country's agriculture is currently practised is severely limited due to growing population pressure combined with a large livestock population. In the short-term, cropped area expansion is also difficult in the lowland areas due to lack of basic infrastructure (particularly roads), shortage of labour for large commercial farming and malaria. Agricultural growth in the short-term therefore depends on raising productivity on smallholder farms in the

[1] *Ethiopian Agricultural Research Organisation*
[2] *University of Western Australia*
[3] *School of Economic Studies, University of Manchester, Manchester M13 9PL, Email: Adam.Ozanne@man.ac.uk*

highlands through the application of new agricultural technology.

Over the last two and half decades various attempts have been made by the Ministry of Agriculture and through agricultural research centres' outreach programmes to increase productivity through the application of new technologies, such as fertiliser, herbicide, pesticide, improved varieties and improved agronomic practices. Yet, despite these efforts, adoption rates remain stubbornly low. Preliminary estimates indicate that fewer than 5% of Ethiopian farmers use improved varieties. Fertiliser use by smallholder farmers is also low: in 1995, on average only 7 kgs nutrient/ha were used in Ethiopia compared to 48 in Kenya and 60 in Zimbabwe (World Bank, 1995). Thus, in terms of area coverage, only 28% of total cultivated land was fertilised and about 1% of cultivated land was planted to improved varieties (CSA, 1995).

The above observations lead to the following questions. What proportion of farmers use new technologies? Why is it that some farmers adopt new technologies while others do not? What factors influence the intensity of adoption of fertiliser and herbicide? Although there have been a number of studies oN the adoption and diffusion of agricultural technologies in Ethiopia (Teckle, 1975; Cohen, 1975; Waktola, 1980; Aklilu, 1980; Ayana, 1985; Kebede *et al.*, 1990; Olana *et al.*, 1995; Yirga *et al.*, 1996; Mekuria, 1996), most preceded recent agrarian reform measures or were limited in scope and area coverage. So these questions have not been comprehensively answered and information regarding the rate and intensity of adoption is still limited. This study therefore examines the adoption and intensity of use of two technologies, fertiliser and herbicide, on two crops, tef and wheat, in the East and West Shewa zones of the central highlands of Ethiopia, an area stretching 250kms to the east and west of Addis Ababa.[2]

2. STATISTICAL MODELS FOR ANALYSING INTENSITY OF ADOPTION

Surveys of innovation adoption typically include zero observations, as do surveys of labour supply and household consumption, and the choice of statistical techniques for dealing with such observations can influence the empirical results obtained (Jones and Yen, 1994). In particular, inappropriate treatment of zero observations can result in biased and inconsistent estimates (Amemiya, 1984). Furthermore, data on intensity of adoption typically take on values of zero and greater than zero, but the Probit and Logit models commonly used to analyse dichotomous adoption data are not suitable for such data (Ghosh, 1991). For example, if a Probit model is used to analyse data on fertiliser adoption, a farmer who adopts the recommended level of fertiliser is treated in the same way as a farmer who applies one tenth of the recommendation.

Alternative models, such as the Tobit, Heckman and double hurdle models which take into account zero observations are available (Tobin, 1958; Heckman, 1976 and Cragg, 1971), but they follow different procedures from each other and therefore produce different results. For example, the Tobit model assumes that decisions regarding adoption and intensity of use are related. However, as noted by Cragg (1971) in the context of the demand for durable goods and Coady (1995) for fertilizer use, such decisions may not be intimately related. Since there appear to be no *a priori* grounds for choosing a single approach, two, the Tobit and Heckman models, are used to estimate the intensity of fertiliser and herbicide adoption on tef and wheat. In doing so, it should be noted that the Heckman model is the most restrictive of the double hurdle models available, in that it assumes that none of the zeros are generated by the consumption decision (i.e. first hurdle dominance) so that standard Tobit censoring is irrelevant (Jones, 1989). The results from the two approaches are then compared to see whether the methodology used influenced the results.

The Tobit Model

The Tobit model has been used extensively to analyse intensity of adoption of technology and demand for durable goods. To specify the Tobit model, let I_i denote an unobservable index variable. The decision making process of potential adopters may be expressed as,

$$\begin{aligned} &y_i = I_i = \beta' x_i + e_i && \text{if} \quad \beta' x_i + e_i > 0 \\ &y_i = 0 && \text{if} \quad \beta' x_i + e_i \leq 0 \\ &e_i \sim N(0, \sigma^2), && i=1,\ldots,n \end{aligned} \qquad (1)$$

where y_i is the observed response for the i^{th} farmer (y_i is continuous for adopters, and $y_i = 0$ for non-adopters). Zero is a critical value of the index. The Tobit model, therefore, measures not only the probability that a farmer will adopt a technology, but also the extent of adoption of the technology once adoption has taken place. If I_i is greater than zero the observed variable y_i becomes a continuous function of the explanatory variables, and zero otherwise. The probability of non-adoption and adoption given characteristics, x_i, is found by,

$$\begin{aligned} &P(y_i = 0) = 1 - F(\frac{\beta' x_i}{\sigma}) \\ &P(y_i > 0) = F(\frac{\beta' x_i}{\sigma}) \end{aligned} \qquad (2)$$

where F(.) is the standard normal probability distribution function evaluated at $(\beta' x_i)/\sigma$ and σ is the standard error. The conditional expectation of the amount used is given by,

$$E\left(y_i \middle| \frac{\beta' xi}{\sigma}\right) = F\left(\frac{\beta' xi}{\sigma}\right)\beta' xi + \sigma f\left(\frac{\beta' xi}{\sigma}\right) \qquad (3)$$

where f(.) is the normal density function. The expected value of the amount of fertiliser and herbicide used, given the knowledge that it is positive, is obtained using the expression:

$$E(y_i | y_i > 0) = \beta' xi + \sigma\left(\frac{f\left(\frac{\beta' xi}{\sigma}\right)}{F\left(\frac{\beta' x_i}{\sigma}\right)}\right) \qquad (4)$$

The Heckman Model

The Heckman model splits the explanation of the observed adoption and intensity level into two components. The first, the adoption decision, is governed by a wholly unobserved latent variable, z_i, where,

$$\begin{aligned} &z_i = \alpha q_i + u_i \\ &Y_i = 1 \;\; if \;\; z_i > 0 \\ &Y_i = 0 \;\; otherwise \end{aligned} \qquad (5)$$

and q is a vector of explanatory variables. The second, the intensity level, is governed by a separate latent variable (y^*_i) which is truncated normal at zero:

$$\begin{aligned} &y^*_i = \beta x_i + \varepsilon_i, \; y^* > 0 \\ &y_i = Y_i * y^*_i \\ &(u, \varepsilon) \sim BVN\begin{pmatrix} 0, & 1 & \sigma\rho \\ & \sigma\rho & \sigma^2 \end{pmatrix} \end{aligned} \qquad (6)$$

where BVN indicates a bivariate normal and ρ is the correlation coefficient between the two residuals, u and ε, which is to be estimated.

This is termed a first hurdle dominance model, because once the first hurdle is cleared one is guaranteed a positive level of adoption: i.e. none of the observed zeros are due to corner solutions in the intensity equation. Although preferable to the Tobit model, this still imposes restrictions on behaviour. In particular, if a variable only appears in vector, x, determining intensity of adoption, it is not possible for changes in that variable to sequentially lead to reduced and then zero intensity; however, if it also appears in vector q in the first hurdle it may have that effect.

Imposing the restriction that $\rho=0$ implies that the adoption and intensity decisions are independent, leading to the complete dominance model which can be estimated as two separate equations: a Probit for the adoption decision, then estimation of the intensity over the positive observations using truncated regression (Greene, 1993).

3. DATA AND EMPIRICAL MODEL SPECIFICATION

For the purposes of this study, farmers who used fertiliser and herbicide on their fields in a specific year were classified as adopters irrespective of the rates they used. Primary data covering personal, household and farm characteristics plus use of resources and technology were collected from a randomly selected sample of 200 farmers using a structured questionnaire. This was supplemented with secondary data collected from a variety of sources. Not all farmers grew both crops, and some incomplete responses had to be discarded, leaving a sample of 151 wheat growers and 190 tef growers with 145 farmers growing both.[3]

Although agricultural intensification efforts in Ethiopia have for many years promoted a full package of technologies, a number of studies (Byerlee & Hesse de Polanco, 1986; Seboka *et al*, 1991 and Dadi, 1998) have shown that farmers select and adopt components of a technological package one at a time rather than a full package. Therefore, separate empirical models were specified for each technology and for each crop, yielding eight models in all.

The definition and measurement of variables thought to affect adoption and intensity of use are given in Table 1. Variable set A consists of farm and farmer specific variables which are used in all models, while set B consists of input or output specific measures of perceptions and risk which are employed in the corresponding models. All variables are used as quantified by respondents except the "index of awareness" (INFO), which is defined as an average of three measures of extension communication (direct visits by development agent, visits to practical demonstrations and participation in

training), and family labour availability (FLBR), which is measured in man-equivalent units.

Table 1: Definition and measurement of variables used in the empirical model specification

Variable	Unit/type	Description/measurement
Dependent		
$IFAD_T$	percent	Fertiliser/ha on tef as percentage of recommended level
$IFAD_W$	percent	Fertiliser/ha on wheat as percentage of recommended level
$IHAD_T$	percent	Herbicide/ha on tef as percentage of recommended level
$IHAD_W$	percent	Herbicide/ha on wheat as percentage of recommended level
Explanatory	Set - A	
Age	Years	Age of household head in years
Education	Dummy	Education of household head: 1 if, literate, 0 otherwise
Gender	Dummy	Sex of household head: 1, if male, 0 otherwise
Location	Dummy	Location of the study area: 1, if East Shewa, 0 otherwise
Farm labour	Man-qui	Family labour availability measured in man-equivalent
Aware	Index	Index of awareness
Farm size	ha	Total land owned by the household measured in hectare
Distance	km	Distance from farm to the market in kilometres
Credit	Dummy	Access to official credit: 1, if credit obtained, 0 otherwise.
Oxen	Number	Number of oxen owned by the household
Explanatory	Set - B	
Price(i)	Dummy	Farmers perception about price of input (i): =1, if response was too expensive, 0 otherwise. I=fertiliser, herbicide
Risk(o)	Dummy	Farmers risk aversion behaviour: =1, if response was yes to the question "Would you apply fertiliser on [output o], if you expect rainfall is insufficient?" 0 otherwise. o = wheat, tef

Rates of adoption of fertiliser and herbicide on tef and wheat in East and West Shewa zones were found to be greater than the national averages. The proportions of farmers in these two zones who adopted fertiliser on tef and wheat were 92% and 61% respectively; thus about 93% and 84% of tef and wheat fields were fertilised in 1995 with application rates of 122 and 93 kg/ha respectively. Post-emergence herbicide was adopted by 74% and 44% of farmers on 70% and 48% of their tef and wheat fields. However, improved varieties were adopted by only 20% and 43% of farmers on 16% and 48% of tef and wheat fields, respectively. Turning to patterns of adoption, about 15% and 27% of farmers used improved varieties, fertiliser and herbicide as a package on tef and wheat in 1995, but very few had adopted all the components of the package in the same year; as mentioned above, most farmers adopted components in a step-wise manner, adding one component at a time until they arrived at the full package. In addition, variations were observed between the rates of adoption of fertiliser and herbicides on the two crops, with rates of adoption for both technologies being generally higher on tef than on wheat. This may arise because tef is the main cash crop in the study areas and therefore receives a higher priority in input allocation.

4. ADOPTION AND INTENSITY OF USE: TOBIT ANALYSIS

Initially, models that included the full set of variables considered relevant on *a priori* grounds were estimated. Of these variables, some were consistently insignificant in the models tested. The impact of such variables on adoption was assumed to be weak. As a compromise between including all, insignificant, variables, and the possibility of excluding marginal but relevant variables, a selection criteria was applied such that those variables which consistently had a t-ratio of less than *one* were omitted and the resulting preferred models were estimated for each technology on both crops.[4] Tables 2 and 3 report the parameter estimates for these reduced specifications for fertiliser and herbicide respectively. The overall fit of the model is reported using the quasi R^2 measure given by

$$R^2 = \frac{2(l_m - l_0)}{2(l_m - l_0) + N} \qquad (11)$$

where l_m and l_0 are the log likelihoods for the full model and a model with just constants in both hurdles, respectively, and N is the number of observations. There is no consensus on the appropriate goodness-of-fit measure for these type of models, and a wide variety are available. Although the one proposed above is not the preferred choice of Veall and Zimmermann (1994) in terms of a Tobit model, the advantage of its use here is that it can be applied uniformly across both the Tobit and Heckman specifications.

Table 2: Factors influencing intensity of fertiliser use on tef and wheat: Tobit estimates for preferred model

	Wheat		Tef	
	Coef.	t-ratio	Coef.	t-ratio
Distance	0.778	*1.94*		
Age	30.323	*2.06*		
Oxen	12.383	*2.62*	7.54	*2.70*
Location	148.75	*9.67*	74.49	*8.66*
Credit			29.63	*2.44*
Constant	-72.1	*5.30*	1.132	*8.56*
σ	84.14		56.60	
LL value	-719.01		-992.81	
R^2	0.35		0.31	

Table 3: Factors influencing intensity of herbicide on tef and wheat: Tobit estimates for preferred model

	Wheat		Tef	
	Coef.	t-ratio	Coef.	t-ratio
Distance	-.0186	*-7.91*	-0.0111	*6.55*
Age	.00554	*2.44*		
Farm size	.0819	*2.59*		
Oxen	.0548	*2.51*	0.0766	*4.53*
Price(H)			-0.155	*2.61*
Constant	.935	*5.30*	1.132	*8.56*
σ	.349			
LL value	-69.27		-86.45	
R^2	0.35		0.25	

It would be helpful if the results from such a comparative exercise generated consistent outcomes, but this is seldom the case and it is not so here. However, there are some common themes. Ownership of oxen has a positive impact on adoption (and hence intensity) in all four Tobit models. The ownership of oxen affects production through its impact on the area cultivated and timeliness of farm operations, and hence makes the use of fertiliser technically more appropriate. Farmers with more oxen may also have greater capacity to absorb the risk associated with new technologies. Being located in East Shewa (coded as 1 in the Location dummy) also has a positive impact on adoption and use of fertiliser on both crops. This may be attributed to differences in infrastructure, institutional factors and agronomic conditions, which the location variable acts as a proxy for, since East Shewa has advantages over West Shewa in terms of physical infrastructure, market opportunities and frequency of water logging problems.

In addition to this broad regional classification, distance to market is significant in reducing adoption rates for herbicide on both crops. This variable is a surrogate for a number of factors reflecting the effects of output price, transport costs and availability of the input on adoption. For farmers who are located far away from the market, output price may not serve as an incentive because of the increased transport costs involved in marketing output and transporting materials from the market to their farms. Availability of fertiliser may also vary with distance to market. In Ethiopia, fertiliser prices are fixed pan-territorially, so there is little incentive for private fertiliser dealers to transport it to distant areas. As a consequence, private fertiliser distributors and retailers tend to concentrate in areas closer to towns. The Agricultural Inputs Supply Enterprise (AISE), a public organisation, is responsible for distribution of fertiliser in remote areas neglected by private distributors and retailers. However, as reported by Demeke (1994), it is inefficient in fertiliser distribution; there may therefore be differences in availability between areas closer to the market and those further away. No consistent effect can be identified for this variable with respect to fertilizer. A number of other variables have differing impacts across the models: age is positively related to adoption of both inputs on wheat, but not tef; and perceived costs of inputs and access to credit appear to play minor roles.

The parameters of the Tobit model are variable across fertilizer and herbicide, because of differences in scale, and cannot be directly interpreted as marginal impacts of changes in the exogenous variables on probabilities of adoption or intensity levels. However, it is possible to provide elasticity measures using the McDonald and Moffat (1980) decomposition, and these are reported for the continuous variables in Tables 4 and 5. Note that in the Tobit specification, a change in an exogenous variable leads to changes in both the probability of adoption and expected intensity level, and are reported here. However, elasticities are difficult to interpret when dealing with dichotomous exogenous variables. Therefore, we report estimated probabilities of adoption and level of intensity for representative farmers, and identify the impact of changes in each of the dummy variables in turn. These values are reported in bold, and may be compared with the "Expected values" given in the final row. It should be noted that these expected values are generated with a

specific set of assumptions, detailed in the notes to the table, and do not represent 'average' estimates.

Table 4: Elasticities and sensitivity of adoption and intensity of fertilizer use

	Wheat		Tef	
	Intensity	Adoption	Intensity	Adoption
Distance	*0.325*	*0.497*		
Education	**58.70**	**0.691**		
Oxen	*0.138*	*0.212*	*0.127*	*0.168*
Location	**161.54**	**0.972**	**90.89**	**0.945**
Credit			**52.67**	**0.792**
Expected values	**39.84**	**0.556**	**31.72**	**0.614**

Variables in italics are continuous variables, those in bold 0-1 dummies. Figures in italics are McDonald and Moffat elasticities, evaluated at mean of continuous variables, and 0 for dummies. The Expected values are expected intensity and probability of adoption evaluated at mean of continuous variables and 0 for dummies. Other figures in bold are expected intensity and adoption generated when the dummy variable under consideration is switched from 0 to 1.

Table 5: Elasticities and sensitivity of adoption and intensity of herbicide use

	Wheat		Tef	
	Intensity	Adoption	Intensity	Adoption
Distance	*-1.918*	*-2.918*	*-1.198*	*-0.456*
Age	*0.383*	*0.478*		
Farm size	*0.274*	*0.342*		
Oxen	*0.151*	*0.188*	*0.221*	*0.084*
Price(h)			**0.327**	**0.806**
Expected values	**0.207**	**0.634**	**0.461**	**0.907**

Variables in italics are continuous variables, those in bold 0-1 dummies. Figures in italics are McDonald and Moffat elasticities, evaluated at mean of continuous variables, and 0 for dummies. The Expected values are expected intensity and probability of adoption evaluated at mean of continuous variables and 0 for dummies. Other figures in bold are expected intensity and adoption generated when the dummy variable under consideration is switched from 0 to 1.

Although consistently significant across all specifications, the elasticity with respect to oxen ownership is relatively low for both adoption and intensity, with a maximum value of 0.22. For herbicide use, the impact of distance to the market is much greater, ranging from -0.46 to -3.00. For fertilizer, the importance of location is clearly revealed. The probability of adoption jumps from approximately 60% to over 95% for both the wheat and tef models as one moves from east to west Shewa. The intensity of adoption shows a similar effect: it quadruples for fertilizer on wheat, and trebles for applications to tef.

5. ADOPTION AND INTENSITY OF USE: HECKMAN ANALYSIS

As noted earlier, Heckman's method of analysis has two parts, the first based on a Probit model and the second on a truncated regression. The estimated coefficients of the models for fertiliser and herbicide adoption on the two crops are shown in Tables 6 and 7, again for the preferred specifications only. For each, the estimates for the intensity and adoption equation are reported together with the estimate of the covariance parameter, ρ. In three cases the latter is significant, implying that biased and inconsistent estimates would be obtained if one considered the positive observations in isolation. As for the results from the Tobit analysis, there are relatively few effects that are common across all four models. However, there are some important differences in the inferences that can be drawn when one compares the Heckman results with the Tobit results.

Table 6: Factors influencing intensity of herbicide on tef and wheat: Heckman estimates for preferred model

	Wheat		Tef	
	Coef.	t-ratio	Coef	t-ratio
Intensity				
Gender			-0.129	*2.26*
Oxen	0.0265	*1.98*	0.0279	*2.15*
Zone	-0.155	*2.96*	-0.111	*2.78*
Constant	0.598	*9.14*	0.659	*9.64*
Adoption				
Farm size	0.313	*2.87*		
Age	0.0241	*2.72*		
Distance	-0.0562	*7.07*	-0.0541	*7.06*
Oxen			0.384	*3.76*
Location	0.572	*2.02*		
Constant	2.13	*3.13*	4.22	*7.25*
ρ	-0.643	*2.39*	-0.379	*1.92*
LL value	050.78		-66.95	
R^2	0.371		0.309	

Table 7: Factors influencing intensity of fertilizer on tef and wheat: Heckman estimates for preferred model

	Wheat		Tef	
	Coef.	t-ratio	Coef.	t-ratio
Intensity				
Fam.labour			-5.33	*2.21*
Oxen			4.45	*1.63*
Zone	65.3	*4.66*	70.26	*7.88*
Price(F)	-32.8	*2.30*		
Constant	150.7	*9.21*	103.4	*9.33*
Adoption				
Farm size			0.983	*1.98*
Age			-0.074	*2.93*
Distance			-0.0764	*2.65*
Oxen	0.319	*3.27*	1.96	*3.28*
Location	1.48	*5.44*	1.73	*2.52*
Constant	-0.490	*1.96*	7.33	*2.76*
ρ	-0.760	*3.37*	-0.484	*1.16*
LL value	-715.50		-979.18	
R^2	0.365		0.387	

In particular, oxen ownership appears to have a positive impact on both intensity and adoption in all cases except intensity of fertilizer on wheat. The location variable is significant in all models apart from adoption of herbicide on tef. Being in East Shewa tends to have a positive impact on adoption in all cases, and a positive impact on intensity of fertilizer. However, for herbicide use, the impact of being in East Shewa is negative. These results illustrate the flexibility inherent in the double hurdle models, of which the Heckman is an example. Indeed, the absence of the location variable in the Tobit models of herbicide use (Table 5) may now be attributed to this bi-polar effect; the Tobit model, with its imposition of a single index variable to determine both adoption and intensity, cannot cope with opposite impacts on the two decisions, and hence reports that the variable has no impact at all.

Table 8 reports elasticities for the continuous variables and estimated adoption probabilities and intensity levels for the discrete variables. Distance from market appears to have a strong impact on the adoption decision, supporting the market access argument for its inclusion. The fact that it is not significant in the intensity equation is telling; once it is available the rate of application is unaffected. Again, the Tobit model would seem to be giving misleading inferences, with the apparently significant impact of distance on intensity in fact being driven by its impact on adoption.

Table 8: Elasticities and sensitivity of adoption and intensity of herbicide use

	Herbicide		Fertilizer	
	Wheat	Tef	Wheat	Tef
Intensity				
Gender		**0.586**		
Farm labour				*-0.185*
Cost(F)			**80.76**	
Oxen	*0.102*	*0.093*		*0.095*
Location	**0.420**	**0.575**	**210.16**	
Expected value	**0.447**	**0.686**	**113.56**	**94.8**
Adoption				
Farm size	*0.768*			*2.41*
Age	*1.224*			*-3.75*
Distance	*-4.254*	*-4.097*		*-5.78*
Oxen		*0.778*	*0.646*	*3.97*
Location	**0.669**		**0.949**	**1**
Expected value	**0.526**	**0.816**	**0.562**	**0.99**

Variables in italics are continuous variables, those in bold 0-1 dummies. Figures in italics are McDonald and Moffat elasticities, evaluated at mean of continuous variables, and 0 for dummies. The Expected values are expected intensity and probability of adoption evaluated at mean of continuous variables and 0 for dummies. Other figures in bold are expected intensity and adoption generated when the dummy variable under consideration is switched from 0 to 1.

6. CONCLUSIONS AND RECOMMENDATIONS

The results show that it is largely structural factors, in particular oxen ownership and distance to market and region, that are determining the adoption and intensity of use of the technologies, rather than personal characteristics, extension activity or attitudes to prices or risk. Farm size and farmers' perceptions of input prices were found to be significant in three of the models estimated, with positive and negative effects respectively, but these effects were not particularly robust across technology or crop mixes, nor across model specifications. The impact of age on adoption and intensity of adoption appears to be both weak, since it was significant in only a few models, and ambiguous, since it had a negative impact on the decision to

adopt fertiliser on tef but a positive impact on the adoption of herbicide on wheat.

Both the modelling approaches used provide evidence of the importance of oxen ownership, although the Tobit results suggest that it affects both the probability of adoption and intensity while the Heckman model suggests its impact is limited to the adoption of fertiliser. However, from the point of view of policy, the important distinction is between those farmers who have oxen and those who have not, since differences in adoption and intensity of use may be expected to widen income disparities between these groups. Furthermore, lack of oxen may encourage farmers to sell land or transfer their use rights on land to other persons, which may in turn increase landlessness, accelerate migration to cities, and eventually exacerbate economic and social problems in urban areas. Thus, attention should be given to solving the traction power problem through the provision of medium-term credit for oxen purchase and short-term credit for veterinary services. Over the past few years credit for oxen purchase has been provided by the Development Bank of Ethiopia and the Commercial Bank of Ethiopia. However, access to this type of credit is very limited. The credit programme requires Service Co-operatives to make an application, sign a loan contract, and assume responsibility (for repayment and purchase of oxen) on behalf of concerned members, and most Service Co-operatives are not interested in such arrangements.[5] The mechanism in place also provides opportunities for corruption and marginalises borrowers. Therefore, a mechanism should be developed whereby non-oxen owners assume responsibility for loans and are fully involved in loan negotiations and arrangements. One possible option would be to establish rural credit co-operatives which could provide credit for oxen purchase and deal directly with the individuals concerned, supervising the programme locally.

Other results worth noting relate to the decline in adoption as distance to market increases and to the effects of differences in location. These outcomes partly arise from variations in market opportunities and differences in availability of infrastructure required for adoption. As distance increases, transport costs increase, depressing the effect of output prices on the one hand and aggravating the effect of input prices on the other. Currently, the private sector shows little interest in providing services in areas far from markets, concentrating on areas which have better infrastructure instead. Under such conditions, establishing and reinforcing grass-roots institutions, particularly Service Co-operatives, is crucial for the development of rural areas and well-being of farmers. Service Co-operatives, when operating efficiently, facilitate access to profitable markets and provide inputs to members at reasonable prices. Financial (i.e. credit) and technical (i.e. training in financial management and administration) support should be provided to these organisations to enable them to improve their services to their members. Investment in physical infrastructure (roads, storage, etc.) may also be expected to result in higher levels of adoption and help to reduce income disparities induced by differential technology adoption between different locations and regions.

The provision of credit is often assumed to play an important role in the adoption of technologies such as fertiliser and herbicides, but was found to be significant in only a few of the estimated models. One of the problems observed in the implementation of the existing formal credit programme was that recovery rates are low, which may have had a detrimental effect on the subsequent availability of credit to farmers. Recently a task force was set up to put pressure on farmers to repay overdue loans. Members of this task force were drawn from wereda, zonal and regional administration offices, agricultural bureaux and banks. However, the sustainability of such a system is questionable and the involvement of the administrative structure and agricultural bureaux in loan collection is undesirable. To achieve a positive impact of credit on adoption, the role of the agricultural bureaux should be limited to educational activities and a mechanism should be devised in which the creditor banks themselves enforce loan disbursement and overdue loan collection.

At the methodological level, the collection of a data set covering two technologies applied to two different crops over a sample of farmers that is largely consistent (some farmers grew either only wheat or tef, so the samples were not identical) has allowed us to explore a number of issues. Firstly, models taken in isolation would suggest that some variables are highly important in the adoption process (for example, age in the Tobit model of herbicide use in wheat). However, the lack of consistency across the four crop/technology mixes (without any strong *a priori* explanation for such differentiation) suggests that these isolated significant coefficients may be spurious. Secondly, the comparison of Tobit and Heckman models suggests that the assumption implicit in the Tobit model that there is a single underlying latent variable driving both adoption and intensity may well be wrong. We would suggest that extending this line of enquiry - by, for example, applying the double hurdle model of Coady (1995) - would be a fruitful way for this form of cross-sectional analysis of adoption to proceed.

NOTES

1. *1 quintal = 100 kilograms.*

2. *Use of these technologies is more widespread in the Shewa zones than in other parts of the country. Thus, approximately 45% of total fertiliser used in the country is consumed in the Shewa zones.*

3. *Full details of the data and sampling method may be found in Dadi, 1998, chapter 6.*

4. *For reasons of space, only the reduced specifications are reported; the unrestricted results and joint tests of restrictions are available from the authors on request.*

5. *The procedure for obtaining credit in Ethiopia involves the following. The individual peasant first sends a request to his or her Peasant Association, which passes it on to a Service Cooperative. All such requests are then forwarded to the relevant wereda office of the Ministry of Agriculture (MOA) for validation. If the requests are found to be in order, the wereda MOA forwards its recommendation to the financing bank. The bank appraises the request and, if approved, a loan contract is signed between the Service Cooperative and the bank. Finally, the bank advises a distributor to deliver the stated input to the individual farmer (Demeke, 1994).*

REFERENCES

AKLILU, B. (1980) The diffusion of fertiliser in Ethiopia: Pattern, determinants, and implication. *The Journal of Developing Areas*, 14:387-399.

AMEMIYA, T. (1984). Tobit models: A survey., *Journal of Econometrics*, 24:3-61.

AYANA, I. (1985) *An Analysis of Factors Affecting the Adoption and Diffusion Patterns of Packages of Agricultural Technologies in Subsistence Agriculture: A Case Study in Two Extension Districts of Ethiopia*. M.Sc. Thesis, Addis Ababa University.

BOCKSTAEL, N.E., STRAND, I.E., MCCONNELL, K.E. & ARSANJANI, F. (1990). Sample selection bias in the estimation of recreation demand functions: An application to sportfishing. *Land Economics*, 66:40-49.

BYERLEE, D. & DE POLANCO, E.H. (1986). Farmers' stepwise adoption of technological packages: Evidence from the Mexican Altiplano. *American Journal of Agricultural Economics*, 68:519-27.

COADY, D.P. (1995). An empirical analysis of fertiliser use in Pakistan, *Economica*, 62:213-234.

COHEN, J.M. (1975). Effects of green revolution strategies on tenants and small-scale landowners in the Chilalo region of Ethiopia. *The Journal of Developing Areas*, 9:335-338.

CRAGG, J. (1971). Some statistical models for limited dependent variables with application to the demand for durable goods. *Econometrica*, 39:829-844.

CSA. (1995). *Agricultural sample survey 1994/95 (1987 E.C.)*. Report on Agricultural Practices (Private Peasant Holdings, Main Seaso) Volume II. Statistical Bulletin No. 132, Addis Ababa: CSA.

DADI, L. (1998). *Adoption and diffusion of agricultural technologies: Case of east and west Shewa zones, Ethiopia*. Ph.D. Thesis, The University of Manchester.

DEMEKE, M. (1994). *Fertiliser procurement, distribution and consumption in Ethiopia*. Paper presented at the Fourth Annual Conference on the Ethiopian Economy organised by the Ethiopian Economic Association, 26-29 November 1994, Debre-zeit.

GHOSH, S.K. (1991). *Econometrics theory and applications*. Prentice-Hall International Editions.

GREENE, W.H. (1996). *LIMDEP user's manual and reference guide version 7.0*. New York: Economic Software, Inc.

HECKMAN, J. (1976). The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimation for such models. *Annals of Economic and Social Measurement*, 5:475-492.

JHA, D. & HOJJATI B. (1994). *Fertiliser use on smallholder farms in Eastern Province, Zambia*. Research Report 94. Washington, D.C.: International Food Policy Research Institute (IFPRI).

JONES, A.M. & YEN, S.T. (1994). *.A box-cox double hurdle model*. IFS Working Paper W94/6 and DERS Discussion Paper No. 94/5.

KEBEDE, Y., GUNJAL K. & COFFIN, G. (1990). Adoption of new technologies in Ethiopian agriculture: The base of Tegulet-Bulga district, Shewa Province. *Agricultural Economics*, 4:27-43.

MCDONALD, J.F. & MOFFAT, R.A. (1980). The uses of Tobit analysis. *Review of Economics and Statistics*, 62:318-321.

MEKURIA, M. (1996). Technology development and transfer in Ethiopian agriculture: An empirical evidence. In Demeke, M., Amha, W., Ehui, S. and Zegeye, T. (eds). *Food security, nutrition and poverty alleviation in Ethiopia*. Proceedings of the Inaugural and First Annual Conference of the Agricultural Economics Society of Ethiopia 8-9 June 1995. Addis Ababa, Ethiopia.

OLANA, G., STORK, H. & DEMEKE, M. (1995). *Farmers' response to new technology in coffee production: the case of small farmers in Ghimbi CIPA, Wellega*. Horticultural Systems in Tropics, Working Paper Series No. 1. University of Hanover, Institute of Horticultural Economics.

SEBOKA, B., NEGASSA, A., MWANGI, W., & MUSSA, A. (1991). *Adoption of maize production technologies in the Bako area, Western Shewa and Welega region of Ethiopia*. Research Report No. 16. Addis Ababa: Institute of Agricultural Research.

STATACORP. (1997). *Stata statistical software: release 5.0*. College Station, TX: Stata Corporation

TECKLE, T. (1975). Application of multivariate probit analysis to adoption model of new agricultural practices. *Ethiopian Journal of Development Research*, 2:43-56.

TOBIN, J. (1958). Estimation of relationships for limited dependent variables. *Econometrica*, 26:24-36.

VEALL, M.R. & ZIMMERMANN, K.F. (1994). Goodness of fit measures in the Tobit model. *Oxford Bulletin of Economics and Statistics*, 56:485-499.

WAKTOLA, A. (1980). Assessment of the diffusion and adoption of agricultural technologies in Chilalo. *Ethiopian Journal of Agricultural Science*, 2:51-68.

WORLD BANK (1995) *Ethiopia: national fertiliser sector project*. Report No. 13722-ET. Agricultural and Environment Division, Eastern Africa Department, African Region.

YIRGA, C., SHAPIRO, B.I. & DEMEKE, M. (1996) Factors influencing adoption of new wheat technologies in Wolmera and Addis Alem areas of Ethiopia, *Ethiopian Journal of Agricultural Economics*, 1:63-84.