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Farm Productivity, Technology Choice, and Nonfarm Income in the Sahel

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Abstract

This paper uses a selectivity framework to model production, input use, and animal traction adoption, using panel data from farm households in two zones of Burkina Faso. Traction adoption is modeled as a function of, inter alia, nonfarm income as a major liquidity source. We calculate average and marginal factor productivities by crop and agroclimatic zone, with an endogenous sample stratification between animal traction users and manual technology users. Four conclusions stand out.

First, animal traction greatly improves land and labor productivity, particularly in more favorable agroclimatic zones such as Burkina's Guinean zone, and in labor-intensive crops (maize and cotton). In the less fertile Sudano-Sahelian zone, animal traction provides less advantage at the margin for land but does at the margin for labor. This is a disappointing in that there is evidence that land constraints are increasing in this zone. The existence of these land constraints is confirmed by the marginal productivity of land being much lower than average productivity in the Sudano-Sahelian zone.

Second, the use of a selectivity model was important to capturing the productivity effect of animal traction adoption. The results suggested that animal traction adoption would increase productivity if manual households had access to traction technology, provided they have the same access to land and other inputs as do current traction households.

Third, beside raising physical productivity, it appears that animal traction increases allocation efficiency in the Guinean zone, perhaps by making farming more flexible: traction households allocate labor in an economically-rational way across crops. Yet households' factor allocation strategies are different in cotton and maize, crops which use inputs intensively and to which higher-quality land is allocated, from millet and sorghum, which are "safety-first" crops, utilizing fewer inputs, and to which lower-quality land is allocated. Policies that increase access to fertilizer and manure assist farmers in intensifying cash crop production. It seems probable that as land constraints grow in the Guinean zone of West Africa, the incentive to complement land-extensive subsistence grain cropping with land-intensive cash cropping will increase. Policies that aid this transition will improve smallholder land productivity.

Fourth, nonfarm income, important to the income strategies of our sample households, greatly affects the adoption of technology, embodied in an expensive package of animal traction equipment, in the Guinean zone. We would not expect own-liquidity sources to be so important unless there were credit market constraints. Policies promoting rural nonfarm activities will help capitalize smallholder African agriculture, in turn raising productivity.

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1. Introduction

Since the series of farm management studies in the semi-arid tropics of Africa in the 1960's and 1970s (e.g. Norman, 1973), land constraints have increased in these zones formerly thought to be land-abundant (Matlon, 1990), factor and credit markets have structurally changed, and nonfarm activity by farm households has apparently greatly increased to the point where in Burkina Faso, for example, it constitutes about half of farm household incomes and four-fifths of cash incomes (Reardon et al., 1992). Moreover, farm households, especially in cash crop zones, have invested in agrarian capital formation, particularly in animal traction. We posit that these changes should affect productivity across farm types and agroecological zones, and make two contributions to knowledge about determinants of agricultural productivity in Africa in this article.

First, past studies in the West African semi-arid tropics (e.g. Barrett et al., 1982, and Jaeger and Matlon, 1990) have either used only one or two years of data, or one agroecological zone, or an aggregate crop category. These have been instructive, but have not been able to inform the debate on intercrop differences, especially between cash and food crops, and on interzone differences, which is an important element of current debate on agricultural research strategy. In this paper, we use a four-year panel over three agroecological zones, in Burkina Faso, stretching from low to high potential areas, and differentiate among the main crops including the subsistence foodgrains, millet and sorghum, and cash crops, maize and cotton.

Second, past farm-level productivity work in Africa tended to use exogenous sample stratification based on farm characteristics -- generally farm size, use of animal traction versus use of manual, i.e. handtool, technology, access to credit, use of new seed varieties, land tenure status, and income stratum. In this article we follow past research by stratifying farm households according to use of animal traction

(a factor we expect to have significant effects on structural production parameters). Our contribution relative to the approach taken in past studies, however, is to endogenously stratify the sample using a binary choice model, an approach rarely taken in productivity research (with a few recent exceptions such as Carter, 1989), and then estimate production functions, controlling for selectivity bias.

This approach also allows us to test the (indirect) effect of nonfarm income on productivity through its effect on technology choice embodied in agrarian capital acquisition. The study of the effect of nonfarm income on capital acquisition is not absent in earlier work (e.g. Barrett et al., 1982, in eastern Burkina), but it has been relatively neglected in farm-level work, and generally neglected in aggregate-level research, because of the rarity of rural nonfarm income data. Yet this intersectoral dimension is important: narrowly focusing farm productivity research on the farm sector means ignoring the context in which farm activities are inserted: rural households, which are "multisectoral firms", husband resources over the year to produce a vector of farm and nonfarm outputs to maximize food security and income, and to manage risk. Off-farm uses of household resources can compete with cropping uses. Yet off-farm income can also increase farm productivity by providing liquidity where access to input credit is limited (common in West African Semi-Arid Tropics; see Christensen, 1989). It can ease households' access to improved production technology, for example to the expensive animal traction package. Since opportunities to generate income from non-farm activities are limited, we posit a positive effect for nonfarm income in investment of animal traction equipment in Burkina. Modeling this effect in a selectivity framework allows nonfarm liquidity to enter the analysis without appearing directly in the production function; it makes more sense that it affect the choice of fixed inputs that in turn determine technology, rather than directly influencing output.

The paper proceeds as follows. In section (2), the selectivity model is discussed. In section (3), the data and zones are described. In section (4), selectivity regression results and marginal factor

productivities between the animal traction (use) group and the manual group (not using animal traction) are discussed. Section (5) concludes.

2. Model

2.1 Model structure

The purpose of the model is to explain productivity differences between farms and zones through the role of agrarian capital, animal traction in the present case.

We start with a production function with the goal of estimating marginal productivities. The production function is given in general form by:

$$Q^i = F(X^i, Z^i), \quad i = 1,\ldots,n \tag{1}$$

where Q^i is the output of crop i using a vector of variable inputs X^i and fixed inputs Z^i.

Estimation of (1) poses the problem of simultaneity bias if the variable inputs and the output levels are simultaneously determined (Marschak and Andrews, 1944). To eliminate this bias, we jointly estimate the production and the variable input demand functions. The input demand functions are derived under the maintained hypothesis that farmers attempt to maximize the returns to the fixed factors, and are given in general form by:

$$X_j^i = f^i(r_1/p_i,\ldots,r_m/p_i, Z_1^i, \ldots, Z_q^i), \quad (i=1,\ldots,n;\ j=1,\ldots,m) \tag{2}$$

where p_i is the price of output i, and r_j the market price of variable input j.

We posit that one consequence of the use of animal traction is to modify the structural production parameters in a significant way. Hence, we estimate (1) and (2) for two sub-samples: AT and manual

farmers. Since AT ownership is likely to be dependent on household characteristics, the sample partitioning is made endogenous by explaining the choice of animal traction. A probit selection rule is chosen:

$$AT^{*} = H\theta + u \tag{3}$$

where AT^{*} is an unobserved latent variable causing households' investment decision. Thus, AT^{*} may be thought of as the expected benefit (known only to the farmer) of investing in animal traction. The observed binary variable, AT, has the value 0 for $AT^{*} \leq 0$ (manual households) or 1 for $AT^{*} > 0$ (households having actually chosen AT). H is a set of household characteristics affecting adoption, Θ is a vector of parameters, and u is a random disturbance assumed to be normally distributed.

This equation also provides information on what drives technology choice at the household level. This is important to know if, as we posit, households that have invested in AT have also attained higher levels of productivity.

To consistently estimate (1) and (2) in the framework of this endogenous sample partition, we follow the two-step procedure of Heckman. First, the binary choice model (3) is estimated and the resulting values of the vector Θ are used to compute the vectors of inverse Mills ratios, $M_1 = \phi/\Phi$ for $AT = 1$ and $M_2 = -\phi/(1-\Phi)$ for $AT = 0$. ϕ and Φ are respectively the density and the cumulative distribution of the standard normal variable evaluated at the point $H_i\Theta$. Second, equations (1) and (2) are estimated for each subsample by including as regressors M_1 in the AT subsample and M_2 in the manual subsample. The resulting estimators are shown to be free from selection bias (Heckman, 1979).

2.2 Regression specification

The production function is chosen to be quadratic, a representation flexible up to the second order:

$$
\begin{aligned}
Q^i_{ht} = a^i_0 &+ \sum_{k=1}^{m} a^i_k X^i_{kht} + \sum_{l=1}^{q} c^i_l Z^i_{lht} + \frac{1}{2}\sum_{j}^{m}\sum_{k}^{m} b^i_{jk} X^i_{jht} X^i_{kht} \\
&+ \frac{1}{2}\sum_{k}^{m}\sum_{l}^{q} g^i_{kl} X^i_{kht} Z^i_{lht} + \frac{1}{2}\sum_{l}^{q}\sum_{r}^{q} d^i_{lr} Z^i_{lht} Z^i_{rht} + \epsilon^i_{ht}, \\
h &= 1,\ldots,N: \quad t=1,\ldots,5; \quad i=1,\ldots,4
\end{aligned}
\tag{4}
$$

where i, h and t index respectively the crop, the household and the year, and j, k, l the inputs. There are 4 crops (millet, sorghum, maize and cotton). The variable inputs include labor and fertilizer, but in implementation, chemical fertilizer was treated as a fixed input because of non-varying prices over the period of observation. The variable labor input is an aggregate of family and hired labor. The Z-vector includes land, manure, rainfall, and toposequence as a proxy for land quality. Manure was treated as a fixed factor because it was essentially a non marketed good.

The estimating form of equation (2) was derived from the first order conditions of profit maximization using (4):

$$
X^i_{Lht} = \frac{1}{b^i_{LL}}\left(-a^i_L + \frac{w_t}{p_{it}} - b^i_{LK}K^i_{ht} - b^i_{LF}F^i_{ht} - b^i_{LM}M^i_{ht}\right) + \mu^i_{ht} \tag{5}
$$

where L, K, F and M stand for labor, land, chemical fertilizer and manure. Crop prices and farm labor wage are included in the price variable vector.

The probit selection rule (2) was specified as follows:

$$AT^*_{ht} = \theta_0 + \theta_1 NONFARM_h + \theta_2 SIZE_{ht} + \theta_3 ROAD_t + \theta_4 AGE_{ht} + \theta_5 TOPO_{ht} + \theta_6 SOILDIV_{ht} + u_{ht}, \quad (h = 1,\ldots,N;\ t = 1,\ldots,5) \tag{6}$$

where NONFARM refers to household non-agricultural income, entering the equation as a cross-section exogenous variable (a constant average over the study period per household). A test of endogeneity (see Appendix) failed to reject the null hypothesis of exogeneity of NONFARM. SIZE is household size in adult equivalents. ROAD is a dummy for good access to a road. AGE is age of the household head. TOPO is an area weighted average of plots' toposequence, and SOILDIV measures households' land quality diversification computed as:

$$1 - \sum_i \left(\frac{\textit{area of quality } i}{\textit{household's total land area}} \right)^2$$

Equation (6) was estimated by maximum likelihood under the assumption that u is normally distributed with a unit variance conditioned on the explanatory variables, which guaranties consistent estimates for the vector Θ. These estimated values were used to compute the inverse Mills ratios which were added as regressors in (4) and (5). The resulting system of equations was estimated using full information maximum likelihood. As the system is nonlinear in both the variables and the parameters (the derived input demand function is nonlinear in the structural parameters), only maximum likelihood estimators are known to be efficient.

All equations were estimated using data (described below) pertaining to two zones of Burkina Faso. Because the survey purposefully assigned an equal number of households to the two technology

strata, the over-representation of animal traction households was corrected by the Manski-Lerman method (Poirier, 1981; see Appendix).

3. DATA AND ZONES

The data are from the survey by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in the five cropping seasons of 1981-1985 in Burkina Faso. The survey covered in detail crop input/output, household nonfarm income, and other household characteristics, in three zones for 150 households. There is no irrigation or tractorization in the study areas. The sample is choice-based such that half of the sample households own traction equipment; the rest use hand tools (and seldom hire traction services).

Due to similar cropping systems and low agroclimatic level, we combined the two northern Sudanian and Sahelian zones into one zone, referred to as the Sudano-Sahelian zone. In that zone, most cropping consists of millet and sorghum, subsistence foodgrains. The number of observations for this zone is 454. Table 1 (parts A and B) shows input use and average factor productivities in the zone. Fertilizer application is very low, only 6 kgs/ha in the traction group and 3 kgs/ha in the manual group. These levels can be compared to use in 1985 in all subsaharan Africa of 9 kgs/ha (and in all developing countries of 58.5 kgs/ha) (Bumb, 1988). Sorghum production is more intensive than millet's, as most of the labor, fertilizer, and manure is applied to sorghum in both animal traction and manual groups.

The southern, Guinean zone, compared to the Sudano-sahelian zone, has much higher agroclimatic level. Animal traction and cash cropping are much more common, and cropping is more intensive and diverse. The Guinean zone is modeled separately using 230 observations. Four principal crops are produced in this zone: cotton and maize (cash crops), and millet and sorghum (subsistence grains). Table 1 (parts C and D) shows that in this zone, production of maize and cotton are twice as labor-intensive as that of millet and sorghum. Fertilizer use is similar between the traction and manual

groups; most is used on cotton and on maize (averaging 111 and 43 kgs/ha respectively, far above the Africa average), with fertilizer use on millet and sorghum averaging only 3 kgs Most manure is also used on cotton and on maize, and traction households use much more due to their greater capacity for transport and application. A simple comparison of the means of manual and animal traction households indicates that total labor use does not differ greatly between traction and manual groups, although animal traction is labor-saving as shown below.

4. RESULTS

4.1 Probit results

The animal traction adoption results are given in table 2. Nonfarm income has a positive effect on the probabilities of adopting animal traction technology. These effects are significant in the Guinean but not in the Sudano-Sahelian.

The probability of adopting animal traction increases substantially with household size. It suggests, along with the effect of nonfarm income, the need for a critical amount of land in order to adopt animal traction.

The combined impact of non-farm income and land (proxied by household size) on the probability of adopting animal traction is given in table 3 for the Guinean zone (where non-farm has a statistically significant effect). This table shows that the probability of adoption increases substantially from low nonfarm income, small farm size households (.08), to high nonfarm income, large farm size households (.89). Among large farms, the probability of adoption almost doubles from 0.38 to 0.70 when one moves from the 5th nonfarm income percentile to the 95th nonfarm income percentile.

These results suggest that non-farm income is the crucial liquidity source for investment in animal traction, a relatively costly package for most farmers. In fact, nonfarm income is a substitute for formal and informal credit to finance such capital acquisition: formal credit mechanisms (such as commercial

banks) do not finance AT investments, nor does the cotton parastatal credit scheme (which is mainly used for purchase of fertilizer), nor does informal credit (from moneylenders in the village) to any significant extent (Christensen, 1989).

4.2 The extent of selectivity bias

The selectivity parameters (coefficients of the inverse Mills ratios) provide a basis for assessing the extent of selectivity bias resulting from subsample estimation. The results are presented in table 4. These coefficients allow the formulation of counterfactual statements about households behavior were they to switch from one technology to the other (see e.g. Shehata, 1991).

All selection coefficients are negative (with the exception of the labor demand equation for millet in the Guinean zone), with half being significant. A negative selectivity parameter for manual households means that had these households rather chosen to use AT, they would be producing more and demanding more labor than the households presently using AT. A negative term for the AT group on the other hand means that had these households chosen to use only manual techniques, they would be producing less and demanding less labor than the households presently using manual technology. This would be the case ceteris paribus (i.e. equal access to land and other inputs).

Overall, the signs and magnitude of the selectivity terms provide a further justification for the use of an endogenous selection model in assessing the impact of technology on Sahel farm productivity. To further validate the model, the Appendix presents the calculated predicted values of the labor demand and output levels together with actual values. One notes that, apart from the labor demand for AT millet and the output and labor demand for manual maize, the predicted values do not differ markedly from the observed numbers.

4.3 Marginal factor productivities

The estimated production parameters from equation (5) are used to compute the marginal productivities to the fixed and variable inputs. Marginal products are computed at the means of the variables, and are multiplied by the average output prices to obtain marginal value products for each zone.

4.3.1 Sudano-Sahelian zone

The marginal value products, MVPs, of labor are significant (table 5). In both crops, in the traction group, the MVPs of labor exceed the average wage rate of 21 francs/hour, while those of the manual group are well below the wage. This implies that animal traction makes labor more productive (twice so) but there is still an excess demand for it on traction farms, perhaps due to constraints in the labor market (e.g, because of temporal covariance over farms in labor use). The labor MVPs are fairly close across crops in both groups, suggesting economic rationality in labor allocation.

Traction households apply much more manure, especially on sorghum as expected. The productivity of manure on sorghum in the traction group is actually more than in the Guinean zone, but in neither zone is the effect of manure on sorghum statistically significant. Very little fertilizer is used on either crop.

The AVPs of labor are well above the MVPs for all crops (although they are relatively close for traction group sorghum). Note that this result is not imposed by model specification because concavity was not imposed. This implies labor constraint. Interestingly, although the traction group's MVPs of labor were much higher than manual group's, the AVPs of labor do not differ much between the two groups.

In the Sudano-Sahelian zone, animal traction does not provide much advantage in land productivity at the margin (on the extra hectare) in the same way that it provided extra productivity at

the margin for labor. The MVPs of land are relatively close over all crops except manual group millet which is somewhat higher. Yet sorghum uses more labor per hectare than does millet, for both groups, and so the millet result is not due to more labor allocation to millet, nor to more fertilizer or manure application, but perhaps to millet better adaptation in the face of climatic stress common in this zone. By contrast, the AVP of land is unambiguously higher for sorghum than for millet, explicable by the greater labor allocation (about 20 percent) to sorghum as compared to millet (beside more fertilizer and manure, albeit at a low level, also being applied to sorghum).

MVPs of land are well below AVPs of land for all but millet in the manual group; this makes sense in that there are limits to fertile land in this zone and much of the new land at the margin is more fragile and of lower quality -- an indication of a land constraint in this zone, corroborated for example by Matlon (1990).

4.3.2 Guinean zone

The marginal value products, MVPs, of labor are significant except that of maize in the manual group. In the traction group, the MVPs of labor exceed the average wage rate of 28 francs/hour except in the case of maize where they are equal; this indicating a relative labor shortage. Moreover, MVPs of labor of the traction group exceed those of the manual group, although they are relatively close for millet. This implies that animal traction makes labor more productive especially in the labor-intensive crops. As in the Sudano-Sahelian zone, there is an excess demand for labor on traction farms, again perhaps due to constraints in the labor market.

In the manual group, MVPs of labor are at (the case of millet and cotton) or below (for maize and sorghum) the wage rate. This implies either excess supply of labor to these crops or a capital constraint to make own-labor more productive for maize and sorghum.

The labor MVPs are fairly close across crops in the traction group, suggesting economic rationality in labor allocation, perhaps due to greater flexibility in resource use afforded by traction. They are not close in the manual group (with millet and cotton close, but maize and sorghum substantially less than the level of the first pair). The average MVP for the traction group (32 francs/hour) is above that of the manual group (22 francs/hour), as traction is labor-augmenting. Traction households also apply more manure. Manure and labor have positive significant interaction effects in most of the estimated models. Manure is mainly applied on the cash crops (cotton and maize) and has a particularly strong and significant effect on cotton in the traction group, as shown in table 6. However, fertilizer MVPs results were positive but unfortunately the standard errors are high and thus the results not statistically significant.

The AVPs of labor are about twice as high as the MVPs, again a result not imposed by model specification because concavity was not imposed. But the average AVP for the traction group (71 francs/hour) exceeds that for the manual group (61), suggesting higher overall labor efficiency in labor-augmenting traction technology, as expected.

The MVPs of land vary by the labor intensity of the crop. For traction households, land MVPs of cotton and maize are higher than those of millet and sorghum. The average MVP of cotton and maize is at least four times that of sorghum and millet. This might reflect: (a) farmers' practice of growing millet and sorghum on lower quality land, (b) much lower use of fertilizer, manure, and hired labor on millet and sorghum, and (c) possibly greater effort and management given to cash crops. Thus, millet and sorghum appear to be treated as subsistence or "safety first" crops. For manual households, the MVPs of land for cotton, maize, and sorghum are higher than that for millet, probably because millet is allocated poorer land. In the manual group, millet, but in the traction group, both millet and sorghum, are allocated marginal, low quality land.

The MVPs of land for the labor-intensive crops (cotton and maize) for the traction group is more than twice that of the manual group; given that labor and fertilizer use by both groups is similar for these two crops, the difference may be due to traction households' greater manure application, greater ability to crop more fertile (but heavier, clay soils), and general greater efficiency of land use.

The AVPs of land again vary roughly according to labor intensity of the crop, with cotton and maize higher than sorghum and millet for traction households, and for manual households, maize is highest, followed by cotton then sorghum then millet. For all households, the AVPs are close between the two cash crops and again between the two subsistence crops, but the average for cotton/maize far exceeds that of sorghum/millet.

5. Conclusions

Four conclusions stand out. First, animal traction greatly improves land and labor productivity, particularly in more favorable agroclimatic zones such as Burkina's Guinean zone, and in labor-intensive crops (maize and cotton). In the less fertile Sudano-Sahelian zone, animal traction provides less advantage at the margin for land but does at the margin for labor. This is a disappointing in that there is evidence that land constraints are increasing in this zone. The existence of these land constraints is confirmed by the marginal productivity of land being much lower than average productivity in the Sudano-Sahelian zone.

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TABLE 1. Input use and average productivities.

A. Sample means of input use per hectare in Sudano-Sahelian zone.

	Animal traction households					Manual households				
	Cotton	Maize	Sorghum	Millet	All	Cotton	Maize	Sorghum	Millet	All
Labor, hours			576	390	464			619	376	449
Fertilizer, kgs			14	1	6			10	1	3
Manure, kgs			333	141	299			246	113	227

B. Average productivity in Francs in Sudano-Sahelian zone[a].

Labor, per hour			35	58				36	42	
Land, per ha			19800	16700				21100	17300	

C. Sample means of input use per hectare in Guinean zone

	Animal traction households					Manual households				
	Cotton	Maize	Sorghum	Millet	All	Cotton	Maize	Sorghum	Millet	All
Labor, hours	938	946	543	451	672	1003	1020	541	512	692
Fertilizer, kgs	109	49	5	2	41	113	36	3	1	37
Manure, kgs	1776	8588	624	226	1345	402	4350	39	28	323

D. Average productivity in Francs in Guinean zone[a]

Labor, per hour	90	72	61	61		57	75	64	48	
Land, per ha	76700	67500	31600	24800		53400	71500	33700	24300	

[a] Output prices used are: cotton 76 CFA/kg, maize 50 CFA/kg, sorghum 60 CFA/kg and millet 65 CFA/kg.

Table 2. Probit results for AT adoption

	Guinean		Sudano-Sahelian	
Variable	Estimate	Std. error	Estimate	Std. error
INTERCEPT	-0.404	0.781	-0.861	1.185
NONFARM	0.694E-06*	0.418E-06	0.967E-06	0.912E-06
SIZE	0.143*	0.028	0.196*	0.0372
ROAD	-0.129	0.269	-1.151*	0.360
AGE	-0.0315*	0.0148	-0.0116	0.0010
TOPO	-0.0703	0.177	-0.193	0.292
SOILDIV	0.0686	0.178	-0.224	0.880
SUDAN			-0.038	0.288
Log likelihood	-98.19		-125.90	
$\phi(\cdot)$	0.360		0.299	

An asterisk (*) denotes significance at the 10 % two tailed level.

$\phi(\cdot)$ is the standard normal density evaluated at $H\Theta$, with H held at the means of its components (equation 4). The marginal effect (at the mean) of each household characteristic on the probability of adoption is obtained by multiplying the estimated parameter by ϕ.

Table 3. Estimated probabilities of AT adoption for different levels of nonfarm income and household size, Guinean zone

HOUSEHOLD INCOME (F CFA)	HOUSEHOLD SIZE		
	LOW (5.06)	MEDIUM (8.69)	HIGH (13.02)
5TH PERCENTILE (27,000)	.077	.183	.389
25TH PERCENTILE (83,553)	.083	.194	.404
MEDIAN (152,883)	.091	.208	.423
75TH PERCENTILE (343,552)	.114	.244	.476
95TH PERCENTILE (1,193,669)	.269	.463	.701
HIGHEST (2,200,000)	.533	.727	.890

All other variables involved in the calculations (see equation 4) are held at their sample means: ACCESS=0.439; AGEHHH=50.31; TOPO=2.08; SOILDIV=0.339. The estimated probability at the sample mean for all variables is 0.324.

Table 4. Selectivity parameter estimates (standard errors in parentheses)

	In production functions (eq.5)		In labor demands (eq.6)	
	AT=1	AT=0	AT=1	AT=0
Guinean zone:				
Millet	-337	-308*	-522*	58.5
	(412)	(131)	(318)	(166)
Sorghum	-44.2	-1700*	-174	-690*
	(235)	(546)	(157)	(252)
Maize	-105	-318*	-35.6	-186*
	(133)	(119)	(55.8)	(52.0)
Cotton	-403	-410	-426	-78.3
	(378)	(593)	(329)	(489)
Sudano-Sahelian zone:				
Millet	-210	-753*	-322*	-743*
	(161)	(238)	(131)	(126)
Sorghum	-410*	-313*	-574*	-710*
	(248)	(169)	(147)	(150)

An asterisk (*) denotes significance at the 10 percent, two-tailed level.

For the interpretation of the results, note that the selectivity parameter is attached to a positive number for the AT regime and to a negative number for the manual regime.

TABLE 5. Marginal value products (evaluated at the sample averages of input use), Sudano-Sahelian

	AT households		Manual households	
	Sorghum	Millet	Sorghum	Millet
Labor, per hour	26.3*	28.6*	13.6*	13.6*
	(3.72)	(4.22)	(1.64)	(3.26)
Land, per ha	138	7940*	9130*	16330*
	(5800)	(2900)	(3490)	(3020)
Fertilizer, per kg	n.a.	n.a.	n.a.	n.a.
Manure, per kg	12.9	9.88	-17.2*	9.10
	(11.2)	(7.35)	(7.02)	(7.09)

An asterisk (*) denotes significance at the 10 percent, two-tailed level. Standard error estimates are in parentheses.

TABLE 6. Marginal value products (evaluated at the sample averages of input use), Guinean zone

	Animal traction households				Manual households			
	Cotton	Maize	Sorghum	Millet	Cotton	Maize	Sorghum	Millet
Labor, per hour	35.0*	28.4*	32.0*	33.6*	28.6*	10.0	19.3*	28.8*
	(4.26)	(5.98)	(5.10)	(4.55)	(4.20)	(8.75)	(5.87)	(5.80)
Land, per ha	40040*	53800	10120*	5310	18440	15400	24670*	9230*
	(14400)	(30850)	(4950)	(5320)	(24900)	(27600)	(9080)	(5280)
Fertilizer, per kg	34.4	50.5	n.a.	n.a.	92.0	170	n.a.	n.a.
	(99.6)	(148)			(200)	(665)		
Manure, per kg	6.31*	0.450	4.80	n.a.	-26.3	0.840	n.a.	n.a.
	(2.96)	(0.855)	(3.37)		(18.5)	(2.11)		

An asterisk (*) denotes significance at the 10 percent, two-tailed level. Standard error estimates are in parentheses.

Table 7. Observed and predicted means of labor demands (hours/household) stratified by crop, animal traction and zone.

	Animal traction households		Manual households	
	Observed	Predicted[a]	Observed	Predicted[a]
Guinean zone:				
Millet	874	1340	441	460
Sorghum	1740	1890	909	686
Maize	399	431	153	92.9
Cotton	2390	2770	1190	1160
Sudano-Sahelian zone:				
Millet	1910	2240	1130	996
Sorghum	1640	2220	711	587

[a] Predicted values computed excluding the inverse Mills ratios.

Table 8. Observed and predicted output means (kgs/household) stratified by crop, animal traction and zone.

	Animal traction households		Manual households	
	Observed	Predicted[a]	Observed	Predicted[a]
Guinean zone:				
Millet	670	968	321	222
Sorghum	1620	1660	925	376
Maize	536	629	199	96.3
Cotton	2780	3140	888	756
Sudano-Sahelian zone:				
Millet	1190	1400	888	757
Sorghum	1050	1460	435	380

[a] Predicted values computed excluding the inverse Mills ratios.

APPENDIX

A. Test for the exogeneity of nonfarm income

There are reasons to believe that nonfarm income may depend on household structure. For instance, larger households may find it easier to spare labor from cropping and household chores to work off-farm. If nonfarm income is endogenous, estimating equation (4) without instrumenting nonfarm income would lead to biased results. Following Rivers and Vuong (1988), we tested and failed to reject the null hypothesis of exogeneity of the income variable, using the following specification:

$$\log(NONFARM_h) = H_{ht}^{*}\,\Pi + \eta_{ht},$$

where H^{*}_{it} contains, besides the right hand variables in equation (6), the following household characteristics:

- dependency ratio
- dummy for single conjugal unit
- dummy for household head=head of compound
- average livestock assets per adult equivalent
- dummy for ethnic group=bwa (only in Guinean zone).

The log-linear specification assured that the predicted values for nonfarm income are positive.

The least squares residuals from the above equation were rescaled (back to the same unit as NONFARM) and the result added as a regressor v_{it} to (6), giving:

$$AT_{ht}^{*} = \theta_1 NONFARM_h + H_{1ht}\Theta + \rho v_{ht} + \epsilon_{ht}$$

where H_1 is the vector of the regressors other than NONFARM in equation (6).

Under the null hypothesis that NONFARM is exogenous, ρ is zero. This was tested using a standard t-test on ρ, and the null hypothesis was maintained for both study zones.

B. Unbalanced sample correction (Lerman-Manski)

This method assigns the following weights to each subsample:

$$\zeta_j = (N_j)/(n_j), \quad j = 0,1$$

where N_j and n_j are the proportions of households with technology j (manual or AT) in the population and in the sample respectively.