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Adoption of Improved Land Use Technologies to Increase Food Security in Burkina Faso: Relating Animal Traction, Productivity, and Non-Farm Income

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ABSTRACT

This article analyzes the determinants of animal traction adoption, and for traction and non-traction groups, the levels of land and labor productivity in Burkina Faso. There are three main conclusions. First, non-farm income was found to be an important indirect determinant of farm productivity, and ability to intensify production, via its effect on animal traction adoption. This was, in particular, the case for the zone where agriculture commercialization is occurring (the Guinean zone). Second, in a region where farmers were traditionally and even today thought to be tied to safety-first, subsistence strategies, our findings show that improved capital and variable inputs—traction and fertilizer and manure, and even labor and best quality land—are applied on cash crops, not on subsistence crops. Third, animal traction greatly improves land and labor productivity, particularly in more favorable agroclimatic zones such as Burkina's Guinean zone, and in the 'intensification crops' that are also the main cash crops (maize and cotton). Traction farmers have an advantage in the quest to intensify farming in a region where population density is increasing rapidly.

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INTRODUCTION

Since the series of farm production studies in the semi-arid tropics of West Africa (WASAT) in the 1960s and 1970s, there have been five fundamental changes in the rural economy: (1) *de facto intensification*: land constraints have increased in these zones formerly thought to be land-abundant; population density has risen, and fallow periods have decreased; (2) *income diversification*: non-farm activity (in wage employment and self-employment) by farm households has increased; (3) *agricultural commercialization*: cash cropping (of food and non-food crops, such as cotton, peanuts, and to some extent, maize) has increased, along with monetization of the rural economy (manifested in the increased importance of cash expenditures on food and non-food items); (4) *farm capital formation embodying technological change*: investment in animal traction equipment has occurred, mainly in cash crop zones; (5) *stagnation* of average yields for the mainly *subsistence grains* (with marketed surplus rates of around 10%, such as millet and sorghum) and *growth in yields of cash crops* (of cotton and, to some extent, of maize and peanuts).

The changes can be hypothesized to form two links, as follows.

First, the first three changes (household income diversification, agricultural commercialization, and the need for farmers to intensify cropping under land constraints) should, in theory, affect technology adoption, embodied in farm capital investment. Non-farm activity and cash cropping earn cash income for farm households; in the presence of capital market constraints and underdevelopment (as one finds in the WASAT) (Tapsoba, 1981; Christensen, 1989), own cash sources should, in theory, be needed for farm investments (Reardon *et al*., 1994*a*, *b*). Earning non-farm income also diversifies a farm household's income, which should make that household more amenable to bearing the risk of making farm investments embodying new technology, and to initiate cash cropping.

Moreover, agricultural commercialization can lead to crop mix changes; in the WASAT, this shift is from millet and sorghum to cotton, peanuts, and maize. Cotton and maize require more fertilizer and manure than millet and sorghum, and cotton production responds better to, and for certain operations relies on, animal traction (Matlon, 1990). Farmers in the WASAT tend to grow cotton and maize on their more fertile soils (Prudencio, 1983); such land is limited, and farmers have incentive to farm them intensely. The influence of cash cropping and non-farm activity on farm capital formation would differ over zones—as a function of agroclimate, of access to infrastructure, and of input credit arrangements. It would also differ over households according to individual incentives and capacity.

Second, farm capital formation is expected to affect the productivity of land and labor—the technical efficiency of the farm. Increasing farm capital should also make farm labor and land allocation more flexible and responsive to changes in incentives and diverse land conditions (Savadogo *et al.*, 1995). Hence, one could expect farm capital formation to increase allocative efficiency as well.

These changes in farm productivity in general translate into changes in farm household incomes, asset holdings, and food security. Thus, there are hypothetical links between agricultural commercialization and income diversification (manifested in cash cropping and non-farm activity), farm productivity, and household income and wealth.

There are grounds for worry here about the implications of these potential links, however. One observes large differences over zones and over households in opportunities for and capacity to participate in both cash cropping and non-farm activity. The differences are due to inter-household differences in initial asset position, and to inter-zone differences in agroclimate, placement of cash crop schemes, and infrastructure. These initial differences in opportunity and capacity can, then, translate over time into increases in 'social differentiation' based on increasingly skewed income distributions. Under certain circumstances this problem could be exacerbated; for example, developing land markets in this context could translate the increasingly skewed income distribution into land concentration and eventually into a phenomenon that is not yet commonly observed in the WASAT, landlessness (Haggblade *et al.*, 1989; Reardon *et al.*, 1992).

Despite the potential importance to rural development and welfare of the previously hypothesized links, there has rarely been an empirical study of it, neither in Africa in general, nor in the WASAT in particular. The exception is the literature on the link between agricultural commercialization and cropping intensification (Adesina and Djato, 1996). But in that work, one does not find study of the link from commercialization and diversification to technology adoption and capital formation, nor the subsequent link to technical and allocative efficiency. An exception to the latter is the link between animal traction adoption and intensification examined in Pingali *et al.* (1989). Barrett *et al.* (1982), in eastern Burkina Faso, hypothesize a correlation between non-farm income and animal traction use, but do not test it empirically.

In the WASAT, the agrarian capital formation studies have focused on animal traction investments, and how they are influenced by population density, relative factor scarcity, and agroclimatic conditions (such as soil type) (see Jaeger and Matlon, 1990). These studies: (1) do not systematically explore across farm households how participation in cash cropping and income diversification, as well as other farm household characteristics, affect adoption of animal traction; (2) do not treat allocative efficiency and physical productivity consequences of animal traction adoption in cash crops *vs* subsistence crops; (3) in general show that animal traction equipment is most commonly used in cash cropping zones; (4) show the potential benefits of animal traction for extensification of cropping (farming more land), but only hypothesize potential land productivity (intensification) effects of the technology.

This paper addresses the gap in the empirical literature by testing the hypothesized relations previously discussed by combining an analysis of technology adoption (embodied in choice of animal traction equipment) with an analysis of the land and labor productivity consequences of that adoption. This analysis takes place in two steps.

First, 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). Past farm level productivity work in Africa has tended to use exogenous sample stratification based on farm characteristics. By contrast, we use an endogenous sample selection framework where technology choice (animal traction) is used to stratify the sample. This endogenous selection involves modeling the adoption choice itself, thus allowing the innovation of including the effects of the household's participation in the non-farm sector, among other things, to be modeled. Modeling the non-farm effect in a selectivity framework allows non-farm liquidity and other household characteristics, such as household size, land entitlements, and experience, to enter the analysis without appearing directly in the production function. This indirect approach makes more sense than a direct approach, as these factors are more likely to affect the choice of fixed inputs that in turn determine technology, rather than directly influencing output.

Second, farm productivity in those subsamples is measured via the estimation of production functions, controlling for selectivity bias introduced by the choice of animal traction. This allows both an exploration of the indirect determinants of productivity via their effect on technology choice, and the direct determinants in the production system. Thus, the two-step method we use to combine technology choice and productivity determination is, despite its utility, rarely used (with a few recent exceptions, such as Carter's study of credit access and farm productivity in Nicaragua; Carter, 1989), but is particularly useful for investigating our hypotheses concerning links.

The analysis uses data from 150 farm households in three agro-ecological zones in Burkina Faso, over four seasons (1981–85); the data cover household characteristics, such as non-farm income and demography, as well as production outputs and inputs for the main crops, including the foodgrains, millet and sorghum, an established cash crop, cotton, and a foodgrain rapidly commercializing, maize. Most African productivity studies have focused on a single crop (often a food crop) and a single agroclimatic zone (Ogbu and Gbetibouo, 1990). By contrast, our analysis covers food and cash crops, to capture the effects of agricultural commercialization, and favorable and unfavorable agroclimatic zones, to capture the agro-ecological effects on technology choice and productivity outcomes.

This paper proceeds as follows. Section 2 discusses modeling considerations. Section 3 presents the regression specification. Section 4 describes the data and zones. Section 5 presents results of the selectivity (traction adoption) model. Section 6 presents allocative efficiency and physical productivity results from the estimation of the production system for the animal traction technology group and the manual technology group. Conclusions are given in Section 7.

MODELING CONSIDERATIONS

This paper models production in the framework of an endogenous sample partition. Sample stratification is based on animal traction ownership, which we hypothesize as being an important determinant of farm level crop production. The model is made up of a system of production and variable input demand functions, with the latter derived from the production function under profit maximization, and a probit selection rule which endogenizes the sample partition into animal traction and manual households.

The model allows us to measure three things: (1) partial factor productivity by crop; (2) technical efficiency across farm types typified by technology used, net of the effects of random factors, as identified by the stage of the production function indicated by the relationship between average and marginal product; and (3) allocative efficiency at farm level, as indicated by the relationship between the marginal value product (MVP) of a factor and the price of the factor.

Our goal is to extract meaningful information from the production data which embody two types of technologies, manual (i.e. using handtools) and traction (i.e. using animal traction) households. A proper way of doing so is to use a sample selectivity model.

We start with the system of production and input demand equations as follows, where Q is crop outputs, X is variable inputs, and Z is fixed inputs:

$$y_{iht} = f(X_{iht},\ Z_{iht};\ \beta) + \epsilon_{iht},\ \ i = 1, ..., n + m, \tag{1}$$

where h and t indicate the household and the time period, y_i is the stacked vector of output i and variable inputs allocated to i, β is a vector of underlying parameters, and ϵ_i is a vector of random disturbances assumed to affect the system additively.

This system is estimated for each of two regimes representing the status of technology. Regime 1 represents households that have adopted animal traction ($AT = 1$); regime 2 represents manual households, i.e. those using hand tools ($AT=0$). It is assumed that a household's decision to select itself into one or the other regime is the result of expected benefits. Technology choice is modeled not as an investment model, but as a binary choice model in the following way:

$$AT^*_{ht} = W_{ht}\theta + u_{ht}, \tag{2}$$

where AT^* is an unobserved latent variable determining households' technology choice. 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 animal traction). W is a set of household characteristics hypothesized to be correlated with adoption, and θ a vector of parameters. This model allows the prediction of the probability of adopting animal traction, given a household with characteristics W.

Once a household selects itself into one regime on the basis of its expectations as to the benefits of animal traction, it faces a given set of production relationships. Equation (1) is, therefore, rewritten for each of the two regimes:

$$y^{AT}_{iht} = f(X^{AT}_{iht},\ Z^{AT}_{iht};\ \beta^{AT}) + \epsilon^{AT}_{iht}\ (h = 1, \ldots, N^{AT}), \tag{3}$$

where the superscript AT takes the value 1 and 0, respectively, for regime 1 ($AT=1$) and regime 2 ($AT=0$); N^{AT} is the number of households in each group. Note that the parameters are allowed to differ between groups.

We use the two-step method proposed by Heckman to correct for selection bias. First, the binary choice model eqn (2) is estimated and the resulting values of the vector θ are used to compute the vectors of inverse Mills ratios, Γ_1 and Γ_0. Second, eqn (3) is estimated for each subsample by including as regressors Γ_1 in the animal traction subsample and Γ_0 in the manual subsample. A test of significance of Γ provides a statistical way of assessing the relevance of the selectivity model.

REGRESSION SPECIFICATION

Production technology

The production function eqn (1) was chosen to be quadratic, a representation flexible up to the second order. The stochastic form of the equations is:

$$
\begin{aligned}
Q_{iht}^{AT} = {} & a_{i0}^{AT} + a_{iL}^{AT} L_{iht}^{AT} + \frac{1}{2} b_{iLL}^{AT} (L_{iht}^{AT})^2 + \sum_{k=1}^{q} c_{ik} Z_{ikht}^{AT} \\
& + \sum_{k=1}^{q} g_{iLk}^{AT} L_{iht}^{AT} Z_{ikht}^{AT} + \sum_{k<l}^{q} d_{ikl}^{AT} Z_{ikht}^{AT} Z_{ilht}^{AT} + \lambda_i^{AT} \Gamma_{iht}^{AT} + \epsilon_{iht}^{AT}, \\
& h = 1, \ldots, N^{AT}: \; t = 1, \ldots, 5; \; i = 1, \ldots, 4,
\end{aligned} \tag{4}
$$

where Γ^{AT} is the inverse Mills ratio taking on the value Γ^0 for the manual households ($AT = 0$) and Γ^1 for the animal traction households. There are four crops (millet, sorghum, maize, and cotton). The only variable input is L, labor, which is an aggregate of family and hired labor. The Z-vector includes fertilizer, land, and manure, treated as quasi-fixed factors, rainfall, and toposequence as a proxy for land quality. Total household land holding is considered a quasi-fixed factor as there is no land market. The area allocated to various crops can be treated as fixed for a given cropping season. Fertilizer is treated as a quasi-fixed input in the sense that its level is predetermined by the credit scheme, and its delivery by the cotton parastatal to the farm household occurs at least a month before the rains start. Current households' needs are assessed before the planting season, based on past uses and on planned current year area, which allows the cotton parastatal to place international market orders for timely delivery. Manure is treated as a fixed factor, because its quantity is determined by households' accumulation of manure prior to planting. The latter point is reinforced by the absence of a market for manure.

The estimating form of the input equations in eqn (1), which reduces to the labor equation, was derived from the first order conditions of profit maximization:

$$
\begin{aligned}
L_{iht}^{AT} = {} & \frac{1}{b_{iLL}^{AT}} \left(-a_{iL}^{AT} + \frac{w_t}{p_{i,\, t-1}} - b_{iLK}^{AT} K_{iht}^{AT} - b_{iLF}^{AT} F_{iht}^{AT} - b_{iLM}^{AT} M_{iht}^{AT} \right) \\
& + \delta_i^{AT} \Gamma_{iht}^{AT} + \mu_{iht}^{AT},
\end{aligned} \tag{5}
$$

where L_i, K_i, F_i, and M_i stand for labor, land, chemical fertilizer, and manure allocated to crop i. w is the wage rate in time t, and p the price of the crop in $t-1$. Note that the number of interaction terms in the production function has been limited in implementation to what the data could support.

Equations (4) and (5) constitute a simultaneous system which embodies the behavioral assumption that households adjust labor over the cropping season after accounting for the predetermined variables and based on other factors subsumed under the error terms and including plant establishment and season outlook. The system was estimated using full information maximum likelihood.

Sample selectivity rule

The probit selection rule eqn (2) defining household technology choice was specified as follows:

$$AT^{*}_{ht} = \theta_0 + \theta_1 NON\text{-}FARM_h + \theta_2 HHSIZE_{ht} + \theta_3 ROAD_t + \theta_4 AGE_{ht} + \theta_5 TOPO_{ht} + \theta_6 SOILDIV_{ht} + u_{ht}, \quad (h = 1, ..., N;\ t = 1, ..., 5), \tag{6}$$

where the variables of the probit are defined as follows: *NON-FARM* is the income from non-cropping sources including income from livestock sales and off-farm activities, measured as a cross-section variable by taking for each household its average annual income over the survey period. The measure thus obtained is a proxy for permanent, expected non-farm income which excludes accidental year-to-year variations. We expect non-farm income to be positively related to technology adoption, as there is evidence that the equipment is costly relative to rural household incomes.[†] Also note that alternative financing sources, such as informal credit or credit from the cotton parastatal, are not generally available for equipment purchase, and that about four-fifths of rural household cash income in this area is from non-farm sources. Non-farm income may be thought to be endogenous to the model, but a test of endogeneity failed to reject the null hypothesis of exogeneity.

HHSIZE is the size of the household, measured in terms of adult equivalents. It is hypothesized that larger sizes are associated with animal traction adoption. Note that farm size is not included in the probit because it is highly correlated with household size.

ROAD is a dummy variable representing the facility of access of the village to regional centers through feeder roads, taking on the value 1 for easy access. This variable captures the differences between villages not accounted for by the other variables.

AGE is the age of the principal decision maker. This variable is expected to negatively affect adoption, as older decision makers are likely to be less prone

[†]An oxen traction package was \$1000 in 1977, a donkey traction package \$500 (Zerbo and Le Moigne, 1977); compare this with \$1500/household income in the Guinean zone of Burkina Faso in 1981–85, of which \$1140 is non-cropping income (Reardon and Mercado-Peters, 1993).

to innovation. However, the relation may be ambiguous, as older people may also have access to more cash and experience, facilitating adoption.

TOPO is an area weighted average of plots' toposequence. Farms with heavier soils in the lower toposequence are likely to adopt animal traction. This variable is, therefore, expected to be negatively correlated with adoption.

SOILDIV measures households' land quality diversity and is computed by the Simpson index using the following formula:

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

We expect *SOILDIV* to negatively influence adoption of animal traction as it implies many small plots and diverse areas difficult to plow.

In the Sudano-Sahelian zone model, a dummy variable, *SUDAN*, is included to represent the Sudanian sample. This variable aims at capturing average location-specific differences between the Sahelian and Sudanian agroclimates.

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 guarantees consistent estimates for the vector θ. These estimated values were used to compute the inverse Mills ratios which were added as regressors in eqns (4) and (5).

DATA AND ZONES

The data used to estimate the model are from the survey by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in the five cropping seasons of 1981–85 in Burkina Faso. The survey covered in detail crop input/output, household non-farm 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 animal traction equipment (to correct for the over-representation of animal traction households following this sampling scheme, we used the Manski-Lerman method (Poirier, 1981)); the rest use hand tools (and seldom hire traction services).

Because of the 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 shows input use and average factor

TABLE 1

Average Household Input Use, Output Levels, and Prices, Per Crop

Guinean zone	*Millet*			*Sorghum*			*Maize*			*Cotton*		
	All	AT = 0	AT = 1	*All*	AT = 0	AT = 1	*All*	AT = 0	AT = 1	*All*	AT = 0	AT = 1
Land												
Area (ha)	1·4	0·9	1·9	2·4	1·7	3·1	0·3	0·2	0·5	1·9	1·2	2·7
Average value product (CFA ha^{-1})		24 300	24 800		33 700	31 600		71 500	67 500		53 400	76 700
Output												
Total (kg)	499	321	670	1280	925	1622	370	199	536	1852	888	2783
kg ha^{-1}	353	361	349	525	542	516	1173	1238	1152	937	744	1019
Labor												
Total (h)	661	441	874	1329	909	1735	278	153	399	1780	1188	2391
h ha^{-1}	469	496	456	546	533	552	880	952	856	911	996	875
Average value product (CFA h^{-1})		48	61		64	61		75	72		57	90
Fertilizer												
Total (kg)	2·5	1·1	3·9	11·8	5·7	17·0	14·2	3·9	24·1	218·4	131·4	302·4
kg ha^{-1}	1·8	1·2	2·0	4·7	3·4	5·4	45·0	24·5	51·8	111·0	110·0	111·0
Manure												
Total (kg)	231	13	442	1090	50	2095	2087	586	3538	2286	443	4067
kg ha^{-1}	164	15	231	448	29	667	6610	3642	7601	1157	371	1488
Prices (F CFA kg^{-1})												
Average	63·6			58·5			52·5			68·5		
Range	40–85			40–81			40–68			55–89		

Table continued on next page

TABLE 1—*contd*

Sudano-Sahelian zone	*Millet*			*Sorghum*		
	All	AT = 0	AT = 1	*All*	AT = 0	AT = 1
Land						
Area (ha)	3·8	3·0	4·0	1·8	1·2	2·8
Average value product (CFA ha^{-1})		17 300	16 700		21 100	19 800
Output						
Total (kg)	1008	888	1189	679	435	1048
kg ha^{-1}	266	295	240	371	376	379
Labor						
Total (h)	1440	1126	1912	1081	711	1638
h ha^{-1}	380	374	386	590	615	576
Average value product (CFA h^{-1})		42	58		36	35
Fertilizer						
Total (kg)	3·8	1·8	6·7	21·2	10·5	37·3
kg ha^{-1}	1·0	0·6	1·4	11·6	9·1	13·1
Manure						
Total (kg)	484	343	697	532	284	904
kg ha^{-1}	128	114	141	291	246	318
Prices (F CFA kg^{-1})						
Average	71			76·4		
Range	40–120			40–108		

productivities in the zone. Fertilizer application is very low, only 6 kg ha^{-1} in the animal traction group and 3 kg ha^{-1} in the manual group. These levels can be compared with use in 1985 in all Subsaharan Africa of 9 kg ha^{-1} (and in all developing countries of 58·5 kg ha^{-1}; Bumb, 1988). Sorghum production is more intensive than millet, as most of the labor, fertilizer, and manure is applied to sorghum in both the animal traction and the manual groups.

The southern, Guinean zone, compared with the Sudano-Sahelian zone, has a 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 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 animal traction and manual groups; most is used on cotton and on maize (averaging 111 and 43 kg ha^{-1}, respectively, far above the African average), with fertilizer use on millet and sorghum averaging only 3 kg. Most manure is 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 later.

RESULTS REGARDING THE DETERMINANTS OF ANIMAL TRACTION ADOPTION

The results of the animal traction technology adoption model are summarized in Table 2. The statistical analysis of the parameter estimates shows that non-farm income (the main cash source, as explained later) has a positive effect on the probabilities of adopting animal traction technology in both the Sudano-Sahelian and the Guinean zones. These effects are significant in the Guinean, but not in the Sudano-Sahelian zone.

The size of the household, measured in terms of active members, has a positive and significant impact on the probability of adoption in the two zones. This suggests that beyond income, labor availability is an important determinant of the adoption of an animal traction package. Indeed, empirical studies suggest that households with four or less members may find it difficult to use traction equipment, particularly for oxen traction.

Road access has an unexpected negative impact on the probability of adoption. This effect is significant in the Sudano-Sahelian, but not in the Guinean zone.

TABLE 2
Probit Results for Animal Traction Adoption

Variable	*Guinean*		*Sudano-Sahelian*	
	Estimate	*SE*	*Estimate*	*SE*
INTERCEPT	−0·404	0·781	−0·861	1·185
NON-FARM	$0{\cdot}694\times10^{-6}$*	$0{\cdot}418\times10^{-6}$	$0{\cdot}967\times10^{-6}$	$0{\cdot}912\times10^{-6}$
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	

$\phi(\cdot)$ is the standard normal density evaluated at $H\theta$, with H held at the means of its components (eqn (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. SE, standard error.
* Significance at the 10% two-tailed level.

The age of the household head has a negative impact on adoption, with this effect being significant in the Guinean, but not in the Sudano-Sahelian zone.

Judging by the hit–miss table at the bottom of Table 2, the variables included are apt in stratifying the sample into animal traction and manual farmers. The proportion of correct predictions is 74% in the Sudano-Sahelian zone and 69% in the Guinean zone. The model is, however, more apt in predicting the correct outcome for non-adopters (97% in the Sudano-Sahelian zone and 95% in the Guinean) than for adopters (39 and 44%, respectively, in the two zones).

We further examine the implications of the results by considering the combined impact of non-farm income and household size on the probability of adopting animal traction. We restrict this to the Guinean zone, where both non-farm income and household size have statistically significant coefficients. The results in Table 3 show that the probability of adoption increases substantially from households with little non-farm income and small farms (0·08), to households with much non-farm income and large farms (0·89). Among large farms, the probability of adoption almost doubles from 0·39 to 0·70 when one moves from the 5th non-farm income percentile to the 95th non-farm 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, non-farm income is the main source of cash income (as noted

TABLE 3
Estimated Probabilities of Animal Traction Adoption for Different Levels of Non-Farm 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)	0·077	0·183	0·389
25th percentile (83 553)	0·083	0·194	0·404
Median (152 883)	0·091	0·208	0·423
75th percentile (343 552)	0·114	0·244	0·476
95th percentile (1 193 669)	0·269	0·463	0·701
Highest (2 200 000)	0·533	0·727	0·890

All other variables involved in the calculations (see eqn (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.

previously), and is a substitute for formal and informal credit to finance such capital acquisition: formal credit mechanisms (such as commercial banks) do not finance animal traction investments, nor does the cotton parastatal credit scheme (which is mainly used for the purchase of fertilizer), nor does informal credit (from moneylenders in the village) to any significant extent.

TECHNOLOGY AND PRODUCTIVITY

The discussion is organized around the three categories discussed in Section 2, differentiating between technology groups of farms: (1) partial factor productivity by crop; (2) technical efficiency; and (3) allocative efficiency.

Differences in partial factor productivities

In general, the animal traction farms are more productive than the manual farms. Moreover, there are also marked differences by zone, factor, and by crop in MVPs of factors. The estimated production parameters are used to compute (at the variables' means) the marginal physical productivities of the fixed and variable inputs. Under constant prices, multiplying the marginal physical products by the average output prices yields the MVPs of the factors for each zone. These are discussed later.

Sudano-Sahelian zone
Animal traction households' labor is more productive at the margin than that of manual households (as the MVPs of labor in millet and sorghum in the animal traction group exceed those of the manual group). Yet AVPs of

labor are similar between the groups. The difference at the margin could be a result of the greater labor-use flexibility afforded by animal traction use.

The choice of the animal traction technology has less impact on land productivity than it does on labor productivity in this zone (possibly because millet and sorghum are the main crops produced). Although manure has a strong coefficient (on sorghum in the animal traction group), neither manure nor fertilizer have statistically significant effects (Table 4). This does not, however, provide solid evidence against the positive effect of fertilizer on yields in this zone, especially on sorghum, but does suggest that it is difficult to capture the effect with low levels of use and the statistical noise of farm survey observations (as compared with field station observations; Sanders *et al*., 1996).

Guinean zone

The MVPs of labor on animal traction farms exceed those on manual farms, especially for the intensification crops that are labor-using—cotton and maize. AVPs of labor are also higher on animal traction farms. Traction is labor-augmenting. The land productivity of animal traction farms in the production of cotton and maize is twice that of manual farms. As labor and fertilizer use is similar between these two groups of farmers, the difference must be due to the greater manure application of animal traction farmers, to their ability to crop more fertile but heavier clay soils, and to their more efficient use of land. Animal traction households apply more manure. Manure and labor have positive significant interaction effects in most of the estimated models. Manure is mainly applied on the 'intensification crops' (cotton and maize) and has a particularly strong and significant effect on cotton in the traction group, as shown in Table 5. However, fertilizer MVPs were positive, but unfortunately the standard errors on the fertilizer coefficients are high and, thus, the results are not statistically significant.

TABLE 4

Marginal Value Products (Evaluated at the Sample Averages of Input Use), Sudano-Sahelian Zone

	Animal traction households		*Manual households*	
	Sorghum	*Millet*	*Sorghum*	*Millet*
Labor (h)	26·3* (3·72)	28·6* (4·22)	13·6* (1·64)	13·6* (3·26)
Land (ha)	138 (5800)	7940* (2900)	9130* (3490)	16 330* (3020)
Fertilizer (kg)	n.a.	n.a.	n.a.	n.a.
Manure (kg)	12·9 (11·2)	9·88 (7·35)	−17·2* (7·02)	9·10 (7·09)

*Significance at the 10%, two-tailed level. Standard error estimates are in parentheses.

TABLE 5
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 (h)	35·0* (4·26)	28·4* (5·98)	32·0* (5·10)	33·6* (4·55)	28·6* (4·20)	10·0 (8·75)	19·3* (5·87)	28·8* (5·80)
Land (ha)	40 040* (14 400)	53 800 (30 850)	10 120* (4950)	5310 (5320)	18 440 (24 900)	15 400 (27 600)	24 670* (9080)	9230* (5280)
Fertilizer (kg)	34·4 (99·6)	50·5 (148)	n.a.	n.a.	92·0 (200)	170 (665)	n.a.	n.a.
Manure (kg)	6·31* (2·96)	0·450 (0·855)	4·80 (3·37)	n.a.	−26·3 (18·5)	0·840 (2·11)	n.a.	n.a.

* Significance at the 10%, two-tailed level. Standard error estimates are in parentheses.

Differences in technical efficiency

Technical efficiency can be identified by the stage of the production function at which the farmer operates—as indicated by the ratio of the marginal to the average product. This ratio is termed the 'production elasticity'; first suggested by Cassels as an indicator of returns to fixed factors (by synthesizing marginal and average products into a single measure).

In general, the elasticities (reported in Table 6) suggest that all farms are in stage 2 of the production process, as all values are between 0 and 1, with the exception of the negative elasticities for manure on cotton and sorghum in the manual subsample in the two zones. This result is not imposed by model specification, as concavity was not imposed, and the quadratic form allows concavity or convexity for any given crop, that is, the farms can be at any stage of the overall production function. Operating in zone 2 is a necessary condition for technical efficiency, and a necessary but not sufficient condition for economic efficiency. Zone-specific results are discussed later.

Sudano-Sahelian zone

There is evidence that labor is less productive at the margin (perhaps because of constraints on access to complementary inputs), and that there is excess supply of labor to the farm—except in the case of sorghum on animal traction farms, AVP of labor exceeds the MVP. The gap is largest for manual farms. This finding is contrary to many farming systems observations in the 1960s and 1970s (Byerlee, 1980) of labor constraints in WASAT agriculture. Yet, the finding of excess labor is reasonable as population density grows; it

TABLE 6

Production Elasticities at the Means of the Inputs

Guinean zone	*Animal traction households*				*Manual households*			
	Cotton	*Maize*	*Sorghum*	*Millet*	*Cotton*	*Maize*	*Sorghum*	*Millet*
Labor	0·39	0·39	0·52	0·69	0·50	0·13	0·30	0·60
Land	0·52	0·96	0·52	0·24	0·35	0·22	0·73	0·38
Fertilizer	0·05	0·04	n.a.	n.a.	0·20	0.06	n.a.	n.a.
Manure	0·13	0·06	0·11	n.a.	−0·19	0·05	n.a.	n.a.

Sudano-Sahelian zone	*Animal traction households*		*Manual households*	
	Sorghum	*Millet*	*Sorghum*	*Millet*
Labor	0·75	0·49	0·38	0·32
Land	0·01	0·48	0·43	0·94
Fertilizer	n.a.	n.a.	n.a.	n.a.
Manure	0·15	0·08	−0·15	0·05

Computed as marginal product divided by average product.

also concurs with findings in many parts of the world of ‘labor surplus’. There is, however, evidence in the 1980s of specific peak intra-seasonal labor bottlenecks, for example for weeding (Cleave, 1974; Delgado, 1979). The returns to land suggests that animal traction farmers are at the end of stage 2 for sorghum, where marginal products approach zero. The AVP of land exceeds the MVP in general, with the exception of millet on manual farms. This implies an abundance of land; but given the high population density and poor land quality, it probably implies constraints to non-land inputs, among which must figure fertilizer and manure.

Guinean zone
Production elasticities with respect to labor are all positive, but less than unity, indicating that both manual and animal traction farms operate on average in stage 2. Elasticities are, however, larger for animal traction than for manual households, for all crops except cotton. This result is interesting, as it suggests that for the major cash crop, the more productive farms are pushing closer to the limit of productivity relative to the less productive farms, thus implying the need for land quality improvement (and, thus, intensification investments) to maintain labor productivity. More generally, the two intensification crops (maize and cotton) require additional complementary input investments compared with the extensification crops, millet and sorghum, for the animal traction households. Production elasticities with respect to land suggest that animal traction farms in the Guinean zone are at the beginning of stage 2 for maize, where the marginal product starts falling short of the average product. The AVPs of land are higher than the MVPs of land for all crops, with the gap being much greater on manual farms, and the gap least on traction farms for cotton and maize. This implies that, while there is evidence of relative land abundance in the Guinean zone, that evidence is much stronger for the subsistence, ‘extensification’ crops (millet and sorghum) and least strong for the ‘intensification crops’.

Differences in allocative efficiency

There are two ways to assess allocative efficiency (economic rationality in allocation of factors): (1) by comparing MVPs across crops for a given category of farm; a lack of equality across crops may indicate lack of economic rationality, or it may indicate constraints in the farming system; (2) by comparing the MVP of a factor and the market price of the factor; a lack of equality may mean lack of economic rationality, or it could mean that the market price does not reflect the true opportunity cost of the factor (the shadow wage) from the household’s perspective (due, for example, to risk factors), or it could reflect constraints on access to a given factor. Here, we can compare MVPs across crops for land and labor, but can only compare MVPs of labor to the market wage, as there is no land market.

Sudano-Sahelian zone

There appears to be excess demand for labor in the animal traction group, as the MVP of labor exceeds the market wage. This could be due to constraints to hiring in the local labor market, because the need for labor is covariant across households. By contrast, there is (overall) excess supply of labor in the manual group, as the MVP of labor is well below the market wage. This could be due to a non-labor constraint—such as constraints to access to animal traction equipment. MVPs of land are similar over crops, with a slight advantage for millet, which makes sense in a drought-prone zone with a crop that is more resistant to climatic stress. Sorghum is also less apt to thrive on the hectare of land at the margin, land that is often of lower quality than the land near the compound. But the AVPs of land (yields) are better for sorghum, which again makes sense, as sorghum is grown on the better land and receives more labor.

Guinean zone

Labor MVPs are nearly equal across crops on animal traction farms, suggesting economic rationality in labor allocation, which is apparently permitted by the resource allocation flexibility that comes with animal traction. By contrast, on manual farms, the MVPs of cotton and millet well exceed those of sorghum and maize, indicating inflexibility in the system and preferential allocation of non-labor inputs to cotton and millet. Moreover, animal traction farmers apply more manure on maize and sorghum, which would raise the product of labor in these crops, allowing a similarity of these two with cotton and millet. Millet is accorded more land, although of lower quality, which makes up (in the labor product) for the dearth of inputs applied to millet.

Moreover, among animal traction households, the MVP of labor exceeds the wage (except in the case of maize), which could indicate a labor constraint. As in the Sudano-Sahel zone, this is probably due to covariance of labor needs across households at key times. Again, as in the other zone for manual farms, the MVP of labor is similar to or less than the market wage, implying (overall) excess labor, probably for the same reasons observed for the Sudano-Sahelian zone—constraints on access to capital (traction, manure, and fertilizer) to raise labor's product. Again, this does not negate the possibility that there is a labor bottleneck at some point in the season.

The MVPs of land (and the AVPs) in the Guinean zone are correlated positively with the labor intensity of the crop. On animal traction farms, the land productivity of cotton and maize well exceeds that of millet and sorghum. This suggests, and the input patterns confirm, that more labor, fertilizer, and manure are applied to cotton and maize; Prudencio also notes that the better land is allocated to them. Farmers in this region, traditionally thought to be without a 'commercial mentality' and steeped in subsistence strategies, are actually keen to allocate the lion's share of soil fertility-enhancing inputs to cash crops.

CONCLUSIONS

Three sets of points are of note regarding the links hypothesized in Section 1.

First, non-farm income was found to be an important indirect determinant of farm productivity, and ability to intensify production, via its effect on animal traction adoption. This was, in particular, the case for the zone where agriculture commercialization is occurring. Non-farm income is the main source of cash income in the area, and credit is generally unavailable for animal traction equipment purchase. Hence, in the Guinean zone, non-farm income affects the household's capacity to buy the equipment, which is an expensive package (controlling for household size and, thus, the need for cultivated land). We would not expect own-liquidity sources to be so important, unless there were credit market constraints. To date, this connection between non-farm income and productivity via animal traction adoption has not been discussed in the literature. Yet there are grounds for worry here. Reardon *et al.* (1994*b*) show that non-farm income is poorly distributed in the WASAT, and that there are significant entry constraints for poor households. This means that this source of inequality in access to cash will translate into inequality in access to agrarian capital and, thus, to productivity. Policies promoting rural non-farm activities in such a way that the poor have access to them will help capitalize smallholder African agriculture, in turn raising productivity and limiting social differentiation in the WASAT countryside.

Second, in a region where farmers were traditionally, and even today, thought to be tied to safety-first, subsistence strategies, our findings show that improved capital and variable inputs—traction and fertilizer and manure, and even labor and best quality land—are applied on cash crops, not on subsistence crops. There is a lesson to be learned on the futility of entering the quest for improving soil fertility and spurring farm productivity only by the door of subsistence crops; rather, the soil fertility and intensification battles need to be fought first and led by cash cropping. There is also support from Dione (1989) for this point, from the cotton zone of Mali.

We found evidence of relative land abundance in the Guinean zone—but the evidence is much stronger for the subsistence, extensification crops (millet and sorghum) and least strong for the cash crops (the intensification crops, cotton and maize). Given rising population densities in the zone, and probably limited access to land of sufficient quality for cotton and maize, we expect that the balance will tip in the near future and land constraints will appear, especially for cotton and maize. Moreover, that manual farms showed much stronger evidence of relatively abundant land, suggests that as access to capital inputs grows, so will land constraints. Those able to intensify will then be the front-runners. In the Sudano-Sahel zone, while there is *a priori* evidence of land constraints in this zone, our findings did not show this land constraint, apparently because other non-land inputs constrain more intensive use of land.

Yet households' land allocation strategies differ between, on the one hand, cotton and maize, crops which use inputs intensively and to which higher quality land is allocated, and on the other hand, millet and sorghum, which are subsistence 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.

Third, animal traction greatly improves land and labor productivity, particularly in more favorable agroclimatic zones, such as Burkina's Guinean zone, and in the 'intensification crops' that are also the main cash crops (maize and cotton). Traction farmers have an advantage in the quest to intensify farming in a region where population density is increasing rapidly. Apart from increasing labor and land use efficiency (apparently mainly through flexibility of resource allocation), traction allows incorporation of soil fertility-enhancing inputs (manure and fertilizer) which are important for cotton and maize. These findings add a crucial empirical dimension to the debate: the literature has traditionally focused on the extensification role of traction, and hypothesized its role in raising and sustaining yields. Here we have identified two ways that traction can spur intensification: (1) via its direct role in increasing land productivity; (2) via its indirect role in facilitating production of the key 'intensification crops' (cotton and maize), the production of which is intensive in labor and improved inputs, and for which yields are much higher than for the subsistence grains, millet and sorghum. In the less-fertile Sudano-Sahelian zone, animal traction provides less advantage at the margin for land, but does raise labor use efficiency.

Moreover, controlling for selectivity bias (in the case of the animal traction stratification) was justified both theoretically and empirically. The use of a selectivity model was important to capture 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 had the same access to land and other inputs as current traction households.

Apart from raising physical productivity, it appears that animal traction increases allocation efficiency of (scarce) labor in the Guinean zone, perhaps by making farming more flexible: traction households allocate labor in an economically rational way across crops.

We found evidence of (general) labor constraints on traction farms—but the opposite on manual farms. The traction finding implies that there are rigidities in the local labor market, perhaps due to covariance across farms of demand for labor. This warrants further study. The finding of the manual farms implies constraints in non-labor inputs (such as traction) that render redundant some own-labor resources. The latter does not negate that there may be peak intra-season bottlenecks of labor demand, as found in linear programming studies.

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