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Population Density, Market Access and Farmer-Generated
Technical Change in Sub-Saharan Africa

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POPULATION DENSITY, MARKET ACCESS AND FARMER-GENERATED TECHNICAL CHANGE
IN SUB-SAHARAN AFRICA

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Introduction

The history of agricultural growth of the developed world illustrates that the rate and direction of technical change are influenced by the economy's land and labor endowments and by the conditions of demand for final agricultural products. The responsiveness of science-based invention and innovation to economy-wide factors has come to be known as the process of induced innovation. Historical and econometric inquiries of U.S. and Japanese agriculture by Hayami and Ruttan (1970) and Binswanger (1974) have verified this endogenous nature of science based technical change.

Farmer-generated technical change is similarly influenced by an economy's population, land endowments and market infrastructure. Population induced changes in traditional food supply systems were examined by Boserup (1965). She concluded that traditional societies across the world have historically devised remarkably similar means of coping with reductions in per capita land availability. Moreover, output growth resulting from these production responses has often been sufficient to cope with the relatively low historic rates of growth in demand from increasing populations.

Boserup's view on the beneficial effects of population growth on total agricultural output has been shared by many economists: Kuznets

(1960), Clark (1968), Phelps (1966), Simon (1977) and Lee (1984) among others. Within a neoclassical framework a few attempts have also been made to formalize the concept of population induced technical change in pre-industrial societies (Stryker, 1976; Daricy, 1980; Pryor and Maurer, 1982; Robinson and Schutjer, 1984). We, however, are not aware of any attempts to empirically test the hypothesis of population-induced technical change proposed by Boserup.

In Boserup's analysis population growth has eight principal effects on farming systems, many of which have also been described systematically by Ruthenberg. These effects are : (1) it increases the intensity of land use, i.e., causes the movement from shifting cultivation to permanent cultivation of land; (2) it increases investments in land improvements especially by drainage, irrigation and terracing; (3) it encourages the shift from handhoe cultivation to animal traction; (4) it encourages soil fertility maintenance via manuring; (5) it reduces the average cost of infrastructure; (6) it permits more specialization in production activities; (7) it induces a change from general to specific land rights; and (8) it reduces the per capita availability of common property resources (forest, bush and/or grass fallows, and communal pastures) (Boserup, 1965, 1975, 1981).

The discussion in this paper will concentrate on effects (1), (2), (3), (4) and (7). The first four of these effects result from the necessity to raise land productivity and to offset the increase in labor requirements associated with more intensive cultivation. The final effect on the transition to specific land rights provides incentives to undertake investments in specific plots, investments which are required for the

intensification of production and the preservation of soil fertility.

This paper first provides a highly stylized utility maximizing model of the following decision variables: the intensity of land use; land investments; soil fertility maintenance; and power source. We show analytically that these decisions can be interpreted as responses to exogenous changes in population density and improvements in market infrastructure. We also show that these decisions vary spatially due to differences in agro-climatic potential.

The major hypothesis consistent with the model are summarized and then tested using two distinct data sets. The first set consists of data from 56 villages in 10 countries across Sub-Saharan Africa and India. This data was collected during field visits in 1983-84 using the group interview technique as part of a larger research effort on agricultural mechanization in Sub-Saharan Africa. The second data set consists of worldwide data on labor use and labor productivity assembled from several research studies and surveys.

Model

Consider a traditional land abundant agricultural society with the following characteristics:

- (i) Utility functions in output and leisure of all persons in the society are identical;
- (ii) All farm households have equal access to cultivation land;
- (iii) There is no locally resident non-cultivating labor class;^{1/}
- (iv) There is no hiring or exchange of labor among residents during the peak labor season, which in this case is the sowing and weeding season;^{2/}
- (v) Rental markets in land do not exist; and
- (vi) There are no rental markets for animal draft equipment and for tractors.

The total amount of land available to the farmer is $A = \bar{A}/N$ where \bar{A} is the total arable land of the community and N denotes the number of people in the community. Denote R to be the land cultivated by the farmer in any given year, and define intensity of cultivation as follows

$$(1) r = R/A$$

Values of r less than one are observed in farming systems that periodically leave a proportion of their land fallow. For example,

^{1/} In land abundant environments the ease of access to land and simple technology imply that a worker's output is at least as large on his own plot as it is on his employer's plot. Therefore, given supervision costs, the employer cannot compensate a worker for the latter's foregone output on his own plot (Binswanger and McIntire, 1986).

^{2/} The absence of hired or exchange labor during peak labor season is because the sowing and first weeding operation are highly time-bound and time-synchronic in most environments. Postponing one's own sowing to work for someone else implies a reduced expected yield because it reduces the expected length of the already short growing season. It also implies higher risks. The optimal timing of the first weeding follows from the timing of sowing; weeding delays reduce yield and increase weeding effort (Binswanger and McIntire, 1986).

$r = .1$ implies that each plot of land is cultivated for 1 year and then reverted to fallow for 9 years, while $r = 1$ implies that each plot of land is cultivated once a year. Values of r greater than one imply multi-cropping systems, for instance, $r = 2$ implies that each plot of land is cultivated twice a year.

Assume that each farmer has a choice between two cultivation technologies: (a) handhoe technology; or (b) animal draft technology. The salient features of each of these technologies are discussed below. In this section of the paper we will attempt to model the farmer's choice of these technologies. We will show that this choice is determined by the land available to the farmer and on the incentives a farmer has for increasing output (foregoing leisure). In other words, we will show that the transition from a handhoe based to an animal drawn plow based technology is directly related to population density and/or improvements in market infrastructure.

Hand cultivation regime

Consider a utility maximizing farmer who wishes to determine the optimal levels of output and labor input within a hand cultivation regime. Define total output per farm as follows:

$$(2) Q_H = Rq_H(r,m) = Arq_H(r,m)$$

where $q_H(r,m)$ denotes output per hectare, which is a function of the intensity of land use (r) and the amount of organic fertilizer used per hectare (m). Subscript H refers to the use of the handhoe technology. Organic fertilizer has to be either in the form of ash, compost or manure. Where animals are not available, manure cannot be used. The production function $q_H(r,m)$ is defined as follows

$$(3) \quad q_H(r,m) = \left(\frac{I}{r}\right)^{\alpha_1} m^{\alpha_2}, \quad 0 < \alpha_1, \alpha_2 < 1 \text{ and } \alpha_1 + \alpha_2 < 1.$$

Where I is an exogenous index of the inherent fertility of the soil and the variable I/r is the actual soil fertility which is positively related to the inherent soil fertility and inversely related to the intensity of land use. Soil fertility declines due to increases in the intensity of land use can be restored by using organic fertilizers. Output is a Cobb-Douglas function of actual soil fertility, organic fertilizer used, and the intensity of land use.

In a handhoe regime the two major tasks for which labor is required are (a) organic fertilizer production; and (b) crop cultivation. The labor requirements for organic fertilizer production are assumed to be a direct proportion of the quantity of fertilizer used per hectare (θm). Where θ is defined as a fraction of a man year spent producing m units of organic fertilizer. The per hectare labor requirement for crop cultivation is given by λr^δ , where λ a positive constant can be interpreted as a fraction of a man year spent on crop cultivation and $0 < \delta < 1$. In other words, per hectare labor requirements for crop cultivation rise with the intensity of land use. This increase in per hectare labor input occurs because: (a) the intensity with which certain tasks have to be performed increases (e.g., as fallow periods become shorter, the land under fallow becomes grassy and higher labor input is required during land preparation in order to get rid of grass roots); and (b) the number of operations which have to be performed increases (e.g., weeding).

In order to get a closed form solution for the indirect utility function a simple utility function is chosen which is concave in output and a negative linear function of labor input L_H

$$(4) \quad U = U(Q_H, L_H) = \left[R \left(\frac{I}{r} \right)^{\alpha_1} m^{\alpha_2} \right]^\beta - \theta m R - \lambda r^\delta$$

$$= A \beta_I \alpha_1 \beta_r (1 - \alpha_1)^\beta m^{\alpha_2 \beta} \theta m r A - \lambda r^{\delta+1} A$$

where β is the elasticity of utility with respect to output, $0 < \beta < 1$, α_1 and α_2 are elasticities of output with respect to soil fertility and organic fertilizer respectively, $0 < \alpha_1, \alpha_2 < 1$ and $\alpha_1 + \alpha_2 < 1$.

The first order conditions for utility maximization are

$$(5) \quad U_r = \frac{\partial U}{\partial r} = (1 - \alpha_1) \beta A \beta_I \alpha_1 \beta_r (1 - \alpha_1)^{\beta-1} m^{\alpha_2 \beta} = \theta m A + (\delta + 1) \lambda r^\delta A$$

$$U_m = \frac{\partial U}{\partial m} = \alpha_2 \beta A \beta_I \alpha_1 \beta_r (1 - \alpha_1)^\beta m^{\alpha_2 \beta - 1} = \theta r A$$

from which we get the optimal levels of r and m , denoted by r_H^* and m_H^* respectively.

$$(6) \quad r_H^* = \left| \frac{\theta A^{1-\beta}}{\alpha_2 \beta I^{\alpha_1 \beta} \left\{ \frac{\lambda (\delta + 1) \alpha_2}{\theta (1 - \alpha_1 - \alpha_2)} \right\}^{\alpha_2 \beta - 1}} \right| \left| \frac{1}{\Delta} = A \frac{1-\beta}{\Delta} X_H \right.$$

$$(7) \quad m_H^* = \left| \frac{\theta^\delta A^{(1-\beta)\delta}}{(\alpha_2 \beta I^{\alpha_1 \beta})^\delta \left\{ \frac{\lambda (\delta + 1) \alpha_2}{\theta (1 - \alpha_1 - \alpha_2)} \right\}^{1-\beta} \alpha_1 \beta} \right| \left| \frac{1}{\Delta} = A \frac{(1-\beta)\delta}{\Delta} Y_H \right.$$

where $\Delta = \{(1 - \alpha_1)\beta - 1 + \delta(\alpha_2\beta - 1)\} < 0$ and X_H and Y_H are implicitly defined in equations 6 and 7.

Comparative statics on r_H^* and m_H^* provide the following results:

- a) $\frac{dr_H^*}{dA} < 0$ A decrease in land area per farmer results in an increase in agricultural intensity.
- b) $\frac{dr_H^*}{dI} > 0$ Areas of higher inherent soil fertility are more intensively cultivated.

- c) $\frac{dr_H^*}{d\beta} > 0$ An increase in the marginal utility of output (resulting perhaps from an improvement in market access) leads to an increase in the intensity of land use.
- d) $\frac{dm_H^*}{dA} < 0$ A decrease in land area per farmer results in an increase in organic fertilizer use per hectare.
- e) $\frac{dm_H^*}{dI} > 0$ Areas of higher inherent soil fertility use higher levels of organic fertilizer per hectare because these areas have shorter fallow periods.
- f) $\frac{dm_H^*}{d\beta} > 0$ An increase in the marginal utility of output leads to an increase in organic fertilizer use per hectare.

The indirect utility function, U_H^* can be obtained by introducing the expression for r_H^* and m_H^* into equation (4).

$$(8) \quad U_H^* = A \frac{\delta\beta(\alpha_2-1)-\alpha_1\beta}{\Delta} \left\{ I \alpha_1 B_X (1-\alpha_1)\beta Y_H^{\alpha_2\beta} - \alpha_X Y_H - \alpha_X^{\delta+1} \right\}$$

$$\frac{dU_H^*}{dA} > 0, \quad \frac{d^2U_H^*}{dA^2} < 0. \quad U_H^* \text{ is a monotonically rising function of } A.$$

As land becomes scarce due to rising population densities, individuals' utility levels decline because the marginal disutility associated with additional effort exceeds the marginal utility associated with additional output produced. It is at this stage that farmers will have an incentive to switch to technologies that increase labor productivity and thereby arrest further declines in utility levels.

Animal traction regime

Let us suppose that a farmer can choose to switch from a handhoe to an animal traction regime at any point in time. Assume that there are no problems in the acquisition of oxen and a plow and that the learning costs associated with animal maintenance and use are minimal.^{3/}

A farmer contemplating a switch from a handhoe to an animal draft regime faces two additional tasks that require his time and effort, these are: (a) labor costs associated with year-round animal care and maintenance; (b) labor requirements for the complete destumping of cultivated land. The cost of destumping (in terms of labor used) is extremely high under forest and early bush fallow systems due to the high density of stumps per unit area and due to the highly developed root network that is difficult to remove. As the length of fallow decreases the cost of destumping declines becoming minimal by the grass fallow stage (fallow periods of 2-3 years). Let us specify the additional labor costs as follows, the costs for animal care: ωC and the cost of destumping land: $\frac{\omega}{r} R = \omega A$.

When a farmer in a handhoe regime switches to animal draft power he experiences substantial labor savings in organic fertilizer production since manure production is possible, he also saves labor in land preparation. We account for these labor savings in the following way: (i) the per hectare labor requirements for organic fertilizer production under an animal traction regime is given by ηM , where η is less than θ the corresponding coefficient in the hand hoe regime and (ii) the per hectare labor requirements for crop cultivation are given by γr^δ , where γ is less

^{3/} We discuss these problems in detail in Pingali, Bigot and Binswanger (1986).

than λ the corresponding coefficient in the handhoe regime.

The utility function of a farmer in an animal traction regime is given by equation (9)

$$(9) \quad U_T = A I^{\beta} \alpha_1^{\beta} r^{(1-\alpha_1)\beta} m^{\alpha_2\beta} - \eta m r A - \gamma r^{(\delta+1)} A - \omega A - \psi C$$

The optimal levels of r and m and the corresponding indirect utility functions are as follows:

$$(10) \quad r_T^* = \left[\frac{\eta A^{1-\beta}}{\alpha_2^{\beta} I^{\alpha_1 \beta} \left\{ \frac{\gamma \alpha_2^{(\delta+1)}}{\eta (1-\alpha_1-\alpha_2)} \right\}^{\alpha_2 \beta - 1}} \right]^{\frac{1}{\Delta}} = A^{\frac{1-\beta}{\Delta}} X_T$$

$$(11) \quad m_T^* = \left[\frac{\eta \delta A^{(1-\beta)\delta}}{(\alpha_2^{\beta} I^{\alpha_1 \beta})^{\delta} \left\{ \frac{\gamma (\delta+1) \alpha_2}{\eta (1-\alpha_1-\alpha_2)} \right\}^{1-\beta + \alpha_1 \beta}} \right]^{\frac{1}{\Delta}} = A^{\frac{(1-\beta)\delta}{\Delta}} Y_T$$

where $\Delta = \{(1-\alpha_1)\beta - 1 + \delta(\alpha_2\beta - 1)\} < 0$, and X_T and Y_T are implicitly defined in equations 10 and 11.

$$(12) \quad U_T^* = A^{\frac{\delta\beta(\alpha_2-1) - \alpha_1\beta}{\Delta}} \left\{ I^{\alpha_1\beta} X_T^{(1-\alpha_1)\beta} Y_T^{\alpha_2\beta} - \eta X_T Y_T - \gamma X_T^{\delta+1} \right\} - \omega A - \psi C.$$

$$\frac{dU_T^*}{dA} > 0, \quad \frac{d^2 U_T^*}{dA^2} < 0$$

Unlike U_H^* which is a monotonically rising function in A , U_T^* reaches a maximum at \tilde{A}_T .

$$(13) \quad \tilde{A}_T = \left| \frac{\omega \Delta}{Z [\delta\beta(\alpha_2-1) - \alpha_1\beta]} \right| \left| \frac{\Delta}{1+\delta-\beta(\delta+1)} \right|$$

where $Z = [I^{\alpha_1\beta} X_T^{(1-\alpha_1)\beta} Y_T^{\alpha_2\beta} - \eta X_T Y_T - \gamma X_T^{\delta+1}]$ and Δ , X_T and Y_T are defined as before. By substituting the expression for \tilde{A}_T in place of A in U_H^* and U_T^* and taking the difference between the two, one can show that U_T^* dominates U_H^* at \tilde{A}_T . A detailed comparison of the two utility functions and the farm size ranges over which one dominates the other is provided in the following sub-section.

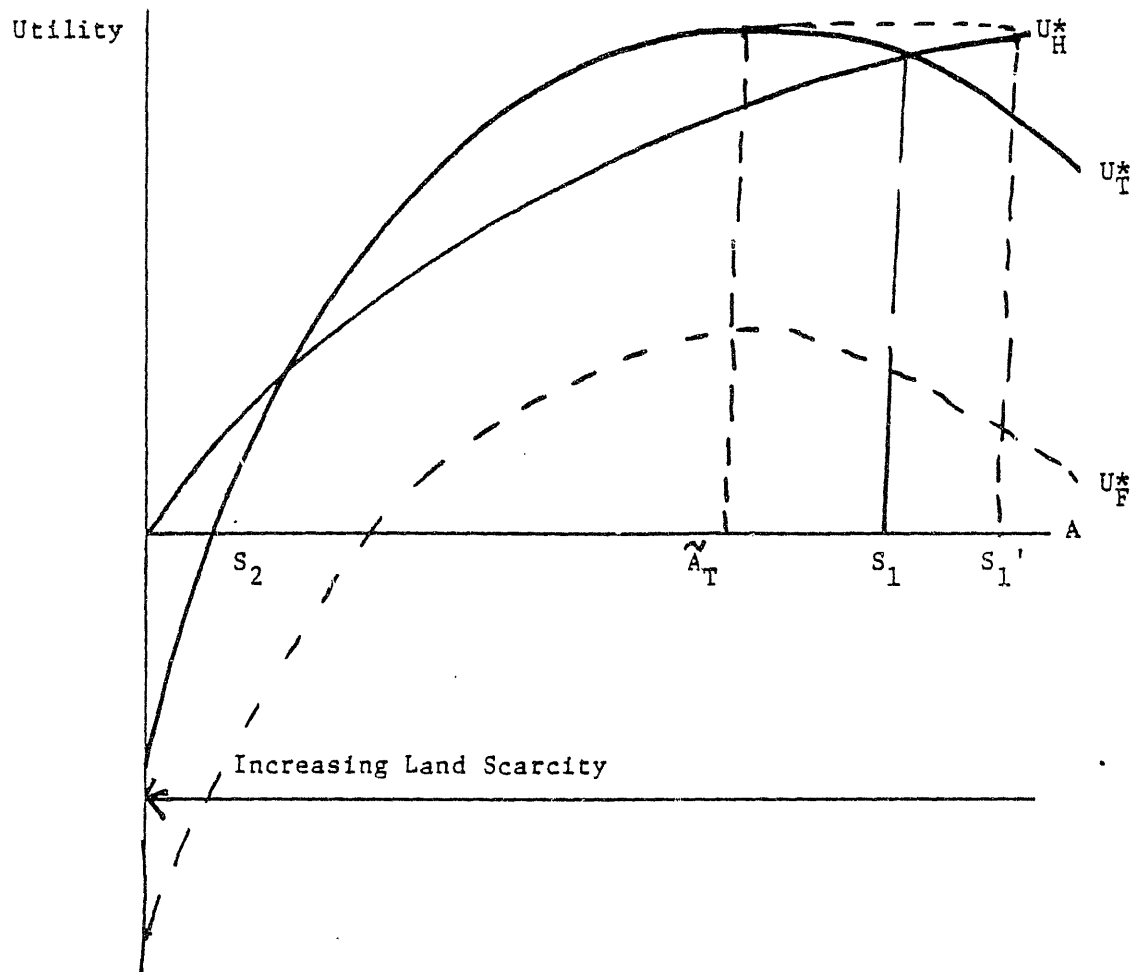
The Switch from a Hand Cultivation Regime to an Animal Traction Regime

The switch from a handhoe based to an animal traction based farming system occurs when the indirect utility function associated with animal technology (U_T^*) dominates the one associated with hand technology (U_H^*). Graph 1 depicts this situation.

The extreme right end of the horizontal axis represents areas where per capita land availability is very high, these are typically sparsely populated areas under shifting cultivation. Movement along the horizontal axis towards the origin indicates a decline in per capita land availability (due to higher population densities) and therefore higher intensities of farming.

For given parameter values, U_T^* dominates U_H^* for all values of A between S_1 and S_2 . In other words, handhoe farmers switch to animal

Graph 1: Indirect Utility Functions Under Handhoe and Animal Traction Regimes



U_H^* : Indirect utility function associated with a handhoe technology.

U_T^* : Indirect utility function associated with an animal draft technology.

U_F^* : Indirect utility function with very high fixed costs for animal maintenance

S_1 : Switch point from handhoes to animal draft technology.

S_1' : Switch point from handhoes to animal draft technology when permanent fallows are allowed.

S_2 : Switch point from animal draft back to handhoes.

A_T^* : The point where U_T^* reaches a maximum.

draft technology at the point S_1 in order to avoid further declines in utility levels. A switch to animal draft technology for values of A greater than S_1 would not be desirable since the marginal disutility associated with the increased labor requirements for destumping fields and for year round maintenance of animals would exceed the marginal utility of output produced with the technology.

The above result holds on the assumption that all the land available to the farmer is either under cultivation or under fallow. Suppose we allowed a third category -- land that the farmer chooses not to cultivate at all, i.e., permanent fallow land, then the switch point to animal draft power is at S_1' . At S_1' the farmer is faced with the choice of declining utility levels under a handhoe technology or maintaining his utility levels by switching to animal draft power. Such a switch would be possible if the farmer cultivates land area \tilde{A}_T while land area $(S_1' - \tilde{A}_T)$ is left under permanent fallow. By making the switch at S_1' the farmer avoids the decline and the subsequent rise in utility levels associated with a switch in technology at S_1 .

One can show that an increase in the value of β leads to an increase in the value of S_1 , i.e., improvements in market access, other things held constant, leads to a switch to animal draft power earlier in the intensification process. The increased utility of output makes it more valuable relative to leisure. This result is reinforced by the complementarity between draft power and manure use.

Graph 1 also shows that for values of A less than S_2 , U_H^* dominates U_T^* . When farm sizes are very small the fixed labor costs

associated with year round care and maintenance of animals far exceeds the utility of additional output, hence farmers revert back to hand cultivation on very small plots of land.^{4/} We have no documentation of cases where such reverse transition back to handhoes has occurred. Moreover, such a transition from animal draft back to hand cultivation is not important in relatively land abundant Sub-Saharan Africa and we will therefore not examine it in the empirical section of this paper.

The above results are relevant when parameter values are such that U_H^* and U_T^* intersect. There are conditions, of course, where such intersection may not occur. For instance, consider the curve U_T^F , this is an indirect utility function associated with animal power technology in an environment with extremely high fixed costs of animal care and maintenance. Some of the animal disease infested zones of Sub-Saharan Africa would be good examples of this situation (trypanosomiasis zones, for example). Under such conditions, hand cultivation would be the dominant technology for all values of A.

Now suppose a farmer had a choice between handhoes and tractors. The switch from handhoes to tractors would require: (a) higher quality of destumping; (b) higher learning costs; and (c) higher fixed costs for maintenance relative to animal traction technology. Moreover, tractor farmers have to forego the manuring benefits available to animal draft farmers. Under these conditions of higher fixed costs, one can show quite easily that the switch from handhoes to tractors would occur later than the switch from handhoes to animal draft (assuming no tractor rental markets).

^{4/} Note that in the real world one might expect draft power markets or inequality in land holdings to emerge, and this result may therefore be a bit artificial.

Therefore, in most situations, a direct transition from handhoes to tractors is not economical and animal draft power is a necessary intermediate stage.

Hypothesis

The following testable hypothesis are consistent with the model presented above:

1. Other things held constant, increases in population density and/or improvements in market access will lead to an increase in the intensity of land use.
2. Other things held constant, increases in population density and/or improvements in market access will lead to the substitution of organic fertilizers for fallow periods in the maintenance of soil fertility.
3. Other things held constant, increases in population density and/or improvements in market access will lead to the substitution of mechanical power for human labor (animal draft power or tractor power).
4. Other things held constant, areas of higher inherent fertility (higher agro-climatic potential) are more intensively cultivated, use higher levels of organic fertilizer and are more likely to switch to mechanical power.
5. Holding the power source constant, an increase in the intensity of land use is associated with declining labor productivity.

6. A change in the power source can be motivated entirely by labor saving benefits and could therefore occur even in the absence of yield benefits.
7. In addition to the above, we will test the Boserup hypothesis on land rights: rights to the acquisition and the use of land become well defined with population growth and/or improvements in market access.

II. Data and Empirical Results

Empirical tests of the above hypothesis were performed on two distinct data sets. Hypotheses 1, 2, 3, 4 and 7 were tested using data from fifty-six villages in ten countries of Sub-Saharan Africa and India. This data was collected using the group interview technique during field visits in 1983-84. See Pingali, Bigot and Binswanger (1986) for further detailed description of this data. Presentation of the hypothesis in terms of two-way tables can also be found in that source. Hypotheses 5 and 6 on labor use and labor productivity were tested using a world wide data set assembled from several published research studies and surveys (see Pingali and Binswanger, 1984, for a detailed description of the data). Discussion of the empirical results will accordingly be separated into two parts based on the data set used.

A. Intensity of Land Use, Technology and Land Rights

The independent variables used in testing hypotheses 1-4 and 7 are population density, market access and agro-climatic potential. The dependent variables are intensity of land use, power source, organic fertilizer use and land availability. Ordered multinomial logit regressions were run on each of the dependent variables relating them to the three independent variables. The following is a description of the variables and the empirical results.

Population density is measured as the rural population per kilometer square within the administrative unit (district) in which the

village is located. This information was obtained either from the agricultural officer in charge of the district or from census records. Market access is a scale variable from 1 to 5, where 1 indicates poor market access and 5 denotes excellent market access. The relative position of the village on this scale was determined by the investigators during the field visits in terms of the distance of the village from an inter-regional road/railroad and the quality of the connecting road (all weather road or dry weather road). Inherent fertility or agro-climatic potential of a location is approximated by the average annual rainfall. The relationship between agro-climatic potential and rainfall is not monotonic, it first rises with rainfall and then begins to decline.

Descriptions of the dependent variables are presented along with a discussion of the empirical results. Table 1 presents the multi-nominal logit estimates.

Intensity of Land Use is defined as the frequency with which a plot of land is cultivated and is measured as a discrete variable from 0 to 5 (0: Forest Fallow; 1: Bush Fallow; 2: Grass Fallow; 3: Emerging Annual Cultivation; 4: Annual Cultivation; 5: Multi-cropping systems). The first multinomial logit estimate in Table 1 shows a highly significant positive relationship between population density and farming intensity. Forest and bush fallow systems are predominant under sparse population densities. As population densities increase one observes the transition to more intensive systems of land use, first to grass fallow, then to annual cultivation and finally to multi-cropping where two or more crops are

cultivated (sequentially) on the same plot each year (hypothesis 1). We have not come across any cases of sparsely populated areas under permanent cultivation systems or cases of very densely populated areas under shifting cultivation systems. Presumably, the former could occur under sparse population densities if market access is excellent, while the latter could not occur even under poor market conditions.

The first multinomial logit regression also shows a very significant positive relationship between market access and the intensity of land use (hypothesis 1). For given population density, an improvement in market access results in more intensive use of existing land resources. Improvements in market access allow for better terms of trade between farm output and imported consumer goods, and thereby accelerate the pace of intensification.

Contrary to our expectation, intensity of land use had a significant negative association with rainfall. This was possibly because of the inclusion of several locations from the humid tropical zone in our sample. Field crop production in this zone is traditionally carried out at low intensities due to the susceptibility of the soils in this zone to high levels of leaching and acidification.

Evolution in Tool Systems Tools used for tillage are defined by a qualitative variable as follows: 0 represents handhoe cultivation systems; 1 represents the emergence of animal traction; and 2 denotes well established animal traction and the emergence of a few tractors in the community. Multinomial logit estimates in column 2 of Table 1 present the

relationship between tools used, population density, market access and agro-climatic potential.

There is a significant positive relationship (at 10% level of significance) between population density and the evolution from handhoes to animal draft power. Also, for given population density, improvements in market access have a very significant positive effect (at 1% level of significance) on the transition to animal draft power. These results verify hypothesis 3.

Rainfall level has a very significant positive effect and the square on rainfall has a significant negative effect on the evolution in tools systems. This indicates that higher rainfall areas (up to a maximum of approximately 1300mm. per annum) tend to switch to animal draft power sooner than areas of lower rainfall.

Organic Fertilizer Use is defined in terms of the labor input required for its production. The movement being from less to more labor intensive techniques for maintaining soil fertility. The variable is denoted as follows: 0 represents no organic fertilizer; 1 represents the use of kraal dust which can be produced with very low labor input; 2 represents limited use of household refuse which requires a moderate level of labor input; and 3 represents manure production.

The very significant positive effect (at 10% level of significance) of population density and market access (at 5% level of significance) are consistent with hypothesis 2. As the intensity of land use increases due to population growth and/or improvements in market

infrastructure, fallow periods are replaced by more and more labor intensive fertilizing techniques such as composting and then manuring.

Changes in Land Rights During our field visits we asked a series of questions that allowed us to determine if and how outsiders could acquire land in a particular village. Outsiders are defined as individuals who are not members of the lineage to which the residents of the village belong. We categorized land acquisition as follows: 0 represents easy access to land, where outsiders could obtain land merely by asking; 1 represents delayed access to land, where outsiders would have to work for a year or more as farm labor before acquiring the privilege to cultivate their own plots; 2 denotes no access to land, where outsiders cannot acquire any land in the village but there are as yet no direct sales of land and 3 represents private property, where direct sales of land are possible and prevalent.

There is a significant positive relationship between access to land, population density and market access (10% and 1% level of significance, respectively). This result verifies hypothesis 7. It is only in sparsely populated locations that we find easy access to land to be generally true. As population densities increase one observes a movement towards privatization of agricultural land. For given population density, areas with better access to the market are more likely to deny outsiders access to land and move more rapidly towards codified private property.

B. Labor Use and Labor Productivity with Farming Intensity

Empirical tests of hypothesis 5 and 6 on labor use and labor

productivity are presented in this sub-section. The data used for this part of the analysis was compiled from the literature. This data set, presented in Appendix 1, contains information on 52 specific locations in Africa, Asia and Latin America. The following variables were used in the analysis: intensity of land use, labor use per hectare, yields, mechanical inputs and land investments.

Intensity of land use was measured by the frequency with which a plot of land was cultivated. Mechanization was defined as the substitution of animal and tractor power for hand cultivation. Dummy variables were used for animal traction, tractor use, and land investment. Land investments include destumping, leveling, drainage, irrigation, etc., the fertilizer use variable includes both organic and chemical fertilizers. Labor input was measured in hours per hectare and yield was measured per hectare and per labor hour.

Labor Use and Intensity of Land Use As discussed by Boserup (1965) and Ruthenberg (1980), holding tools constant, the total labor input per hectare on a given crop is positively correlated with the intensity of farming. The increase in labor input occurs because: (a) the number of operations which have to be performed increases (e.g., manuring, irrigation, etc.), and (b) the intensity with which certain tasks have to be performed increases (e.g., land preparation and weeding). Table 3 shows how the operations performed increase with the intensification of the farming system. A log-linear regression was used to test the hypothesis of a positive correlation between labor use and the intensity of land use.

The results of the regression are presented in Table 2. Intercept dummies were used for animal traction, tractor use and land investments. Since our earlier model treats labor input and choice of technique both as decision variables, these regressions represent a correlation analysis, but do not establish causality as did the regressions in Table 1.

The hypothesis that the transition to more intensive systems of land use are associated with longer working hours is validated. A 10% increase in intensity of land use is associated with a 4.6% increase in labor-use per hectare. This positive relationship between land use intensity and labor use per hectare holds true irrespective of the types of tools used. The data set was separated by each type of tool and the coefficient on farming intensity estimated. The null hypothesis of equality of coefficients could not be rejected.

Animal traction and tractor use act as intercept shifters. For given intensity of farming the switch to animal traction or tractors is significantly associated with a reduction in the total labor use per hectare. Land investments were not found to significantly affect labor use in cultivation. However, the labor use data generally did not include the time spent for investments such as destumping, levelling, irrigation, etc., and for the maintenance of animals and machines. This overhead labor obviously does increase with land investments.

Results presented in Table 2 also validate the hypothesis that yield per hectare rises with intensity of land use, holding the level of mechanization constant. A 10% increase in land use intensity is associated with a yield increase of 3.9%. The level of mechanization on the other

hand is not significantly associated with yield. On the other hand, for given intensity of land use, land investments are associated with yield increases of 30%.

Land use intensity was not significantly associated with output per man-hour though the negative sign on the coefficient was as hypothesized. The decline in output per man-hour of cultivation labor may have been prevented by additional capital investments in land. The additional labor required for these investments is not reflected in this data set. It is likely that output per man-hour of total labor (cultivation and overhead) would show the hypothesized declining trend. Labor productivity is positively associated with mechanization: for given intensity, output per man-hour is 78% higher on animal traction farms than on handhoe farms and 42% higher on tractor farms than on animal traction farms.

Conclusions

1. This paper provides empirical support to Boserup's thesis on population induced technical change in traditional agricultural societies. In addition to population growth we show that improvements in market access through better transport infrastructure have similar effects on technical change. This paper shows that an increase in population density and/or improvements in market access cause a reduction in fallow periods due to increasing land scarcity and therefore lead to the evolution of the agricultural system from shifting cultivation to permanent cultivation of land. Intensification of land use is generally associated with increased labor requirements per hectare, and therefore diminishing returns to labor when technology is held constant.

2. Far from being immobile and technologically stagnant "traditional" African societies have responded to changes in population densities and external markets with changes in farming systems, land-use patterns, technology and institutions along systematic and predictable patterns.

3. The switch from the handhoe to animal drawn plows and later to tractors is closely associated with the evolution of farming systems. This switch is induced by the labor saving benefits associated with animal draft and tractor power. The switch to animal drawn plows occurs around the short fallow stage and not before because it is only at this stage that the overhead labor costs for destumping and leveling fields and for training, feeding and maintaining animals are offset by benefits in terms of labor

savings. The substitution of fallowing first with simple and then with more evolved manuring techniques is likewise related to the evolution in farming systems.

4. Institutional arrangements for the acquisition of land by individuals within the group and by "outsiders" are not rigid but do change as increasing population densities or improved market access makes land scarce. Land acquisition which is extremely easy under shifting cultivation becomes more and more difficult as intensification leads to more narrowly defined groups or lineages and therefore results in the exclusion of large numbers of people from acquiring the rights to cultivate. The ultimate institutional change, and one which commonly occurs under high population densities is one of clearly defined private property rights with the ability to buy and sell land.

5. As we know from research on developed countries, declines in labor productivity can be offset and more than offset by mechanical inputs and biological technologies. All countries of the developed world have achieved rates of labor and land productivity sufficient to outstrip their rates of population growth. This cannot, however, be cause for assuming that rapid population growth presents no problem. First of all, developing country population growth rates exceed historical rates in developed countries substantially. Moreover, the biological technologies required often have to be invented or adapted. They cannot simply be pulled from a shelf. In a number of countries the institutional capacity to invent these technologies is rudimentary at best. Even the mechanical technologies require adaptive learning. They also require capital accumulation of a

magnitude which is very hard to achieve given current capital endowments of the societies.

6. The potential problems of declining labor productivity or of environmental degradation are not problems of levels of population densities. Given sufficient time it is likely that a combination of farmer inventions, savings, development of research institutions and institutions to deal with land tenure and soil degradation issues will be able to accommodate much larger than current population in most countries, and especially in many of the low density ones. However, when populations grow rapidly, all these changes in technology and institutions are required rapidly and simultaneously and they may fail to emerge at a sufficiently rapid pace to prevent decline in human welfare.

Table 1: Ordered Multinomial Logit Estimates

Dependent Variable Independent Variable	Intensity of Land Use (1)	Tools Used (2)	Organic Fertilizer (3)	Land Availability (4)
a ₁	5.04 (2.53)	-4.57 (2.53)	0.024 (2.42)	21.05 (11.456)
a ₂	2.42 (2.40)	-6.66 (2.54)	-1.92 (2.44)	19.70 (11.45)
a ₃	0.77 (2.39)	-9.27 (2.73)	-2.59 (2.45)	16.40 (11.37)
a ₄	-0.03 (2.40)	-	-	-
a ₅	-2.47 (2.44)	-	-	-
Population Density (per km ²)	0.019*** (0.005)	0.007* (0.004)	0.008* (0.004)	0.038*** (0.013)
Rainfall (mm/year)	-0.007** (0.003)	0.008*** (0.003)	-0.0004 (0.004)	-0.05
Rainfall Sq.	0.000002 (0.000001)	-0.000003*** (0.000001)	-0.0000007 (0.0000014)	0.00003
Market Access	0.875*** (0.27)	0.658*** (0.26)	0.67*** (0.28)	0.95** (0.46)
R.	0.475	0.315	0.377	0.608

Notes

(i) Standard errors are given in parentheses.

(ii) *, **, *** denote significance levels of 10%, 5% and 1%, respectively.

(iii) a₁-a₅ are intercepts used in estimating the probability that the dependent variables takes a certain value. For instance,

$$P(Y \geq j) = \frac{1}{1 + e^{-(a_j - x\beta)}}$$

Table 2: Intensity of Land Use Related to Labor Use Per Hectare
Yield Per Hectare, Yield per Hour of Cultivation Labor

	Log Labor Use Per Hectare	Log Yield per Hectare	Log Yield/ per Hour of cultivation Labor
Log Land Use Intensity	0.456*** (0.132)	0.389*** (0.097)	-0.068 (0.15)
Animal Traction	-0.96*** (0.23)	-0.179 (0.17)	0.78*** (0.26)
Tractor	-1.14*** (0.27)	0.068 (0.20)	1.20*** (0.31)
Land Investments	0.057 (0.20)	0.299** (0.148)	0.24 (0.23)
Intercept	5.46	5.69	0.24
R ²	0.33	0.45	0.38
Number of Observations	56	56	56

Notes

- (i) *** significant at 1%; ** significant at 5%
- (ii) Standard errors are given in parentheses.
- (iii) Does not include labor use in overhead activities such as land investments and animal or machine maintenance.

Table 3: Comparison of Operations across Farming Systems

Operations	Systems				
	FF	BF	SF	AC	MC
Land Clearing	Fire	Fire	None	None	None
Land Preparation & Planting	No land preparation digging sticks used to plant roots and sow seeds	Land is loosened using hoes and digging sticks	Use of plow for preparing land	Animal drawn plows and tractors	Animal drawn plows and tractors
Manure Use	<ul style="list-style-type: none"> - Ash - Perhaps household refuse for garden 	<ul style="list-style-type: none"> - Ash - Sometimes chitemene techniques - Household refuse for garden plots 	<ul style="list-style-type: none"> - Animal dung or Manuring - Sometimes composting 	<ul style="list-style-type: none"> - Manure, sometimes human waste - Composting - Cultivation of green manure crops - Chemical fertilizers 	<ul style="list-style-type: none"> - Manure, sometimes human waste - Composting - Cultivation of green manure crops - Chemical fertilizers
Weeding	Minimal	Required as the length of fallow decreases	Intensive weeding required	Intensive weeding required	Intensive weeding required
Use of Animals Farming	None	As length of fallow decreases animal drawn plows begin to appear	<ul style="list-style-type: none"> - Plowing - Transport - Interculture 	<ul style="list-style-type: none"> - Plowing - Transport - Interculture - Post-harvest tasks - Irrigation 	<ul style="list-style-type: none"> - Plowing - Transport - Interculture - Post-harvest tasks - Irrigation
Seasonality of labor demand	Minimal	Weeding emerges as a peak	Land preparation, weeding and harvesting	Land preparation, weeding and harvesting	Acute peak around land preparation, harvest, and post-harvest tasks
Fodder Supply	None	Emergence of grazing land	Abundant open grazing	Open grazing restricted to marginal lands and stubble grazing.	Intensive fodder management and fodder crop production.

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