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Population Density, Agricultural Technique
and Land Utilization in a Village Economy

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For many years our view of the relationship between population density and agricultural productivity in less-developed countries has been dominated by the heritage of Thomas Malthus. Population in these areas is seen historically to be limited chiefly by the means of subsistence. Given an improvement in agricultural technology, the density of population increases, reducing the marginal and average product of labor, until per capita consumption is again at the subsistence level. Only if technological progress can be sustained and birth rates brought under control is it possible to escape from this trap (see Harvey Leibenstein, Dale Jorgenson).

A contrasting view has recently been set forth by Ester Boserup. Instead of population density being determined by productivity in agriculture, it is agricultural techniques which have for centuries been altered in response to changing population density. Aside from the disagreement between the Malthusians and Mrs. Boserup over the direction of causation and the empirical question of the relative ease with which farming practices may be changed, there is another fundamental issue. The Boserup view is that the intensification of agriculture is not an improvement, as is commonly argued, but is a response to the increased scarcity of land actually resulting in a decrease in output per manhour. In the Malthusian view, on the other hand, intensification can only arise after there has been technological progress. In terms of the analysis presented in this paper, Mrs. Boserup envisions only a movement along the production function whereas the Malthusians speak of an initial upward shift followed by a movement along the function.

The crucial distinction between the two views has to do with the factors limiting population growth. To the Malthusians, until birth rates

begin to fall under the impact of modernization, population growth is limited chiefly by the rate of technological progress in agriculture. Mrs. Boserup, on the other hand, believes that other factors have been more important.

Numerous writers have observed the wide range of population densities which exist throughout the less-developed world (see William Allan, John Hopkins, and Karl Pelzer). The reasons for these varying densities are not well understood. The maximum population density in any given region which can be supported without the introduction of modern inputs from industry appears to be determined by conditions of climate and soil. Yet it is only in a relatively few areas that these limits seem already to have been reached.

Where population densities are not at this absolute maximum, there is less knowledge of the limiting factors. Population control has been practiced among many societies, non-literate as well as literate, but little is understood of the balance between these measures and those designed to speed the rate of innovation and permit the land to support larger numbers. Nor is much known of the relative importance of death from disease, wars, or famine due to pestilence or climatic unpredictability, or of the constraints imposed on inward or outward migration.

An important ingredient in understanding the relationship between land and the population it supports is a theoretical explanation of land utilization. Mrs. Boserup has made another important contribution, here, in relating systems of land tenure to population density. Her discussion is largely descriptive, however, and deals with societies as a whole rather than with the choices facing individual decision-makers within the society.

In this paper a model of land and labor utilization is presented with the village as the decision-making unit. Used in the model is a production function of the type described by Mrs. Boserup and discussed in the first section of the paper. The model itself, which allows for the implicit cost in terms of time of using land in relatively sparsely populated regions, is outlined in the next section. The effects of changes in village population and of the spread of cash crops are also analyzed. The third part of the paper describes a body of empirical information which is consistent with the model. Much of this information pertains to Africa, where population densities are generally lower than for most other continents, but the analysis has relevance for Asia and Latin America as well. In the final section, conclusions are drawn and some implications for policy suggested.

I. The Boserup Hypothesis

In her book, Mrs. Boserup has assembled an impressive array of historical evidence to demonstrate the vast range over which population densities can be supported at a subsistence standard of living without the use of any factory-produced agricultural inputs. Where very extensive farming techniques are used there are few problems of maintaining soil fertility. Fallow periods are very long, perhaps twenty-five years. Prior to planting, trees and brush are burned to clear the land, and the ashes are raked into the soil to increase fertility. As fallow periods are shortened with increased population density, the lesser natural regeneration of

the soil plus the smaller amount of vegetation which has grown up during the fallow period require that additional brush be brought to the fields for burning. Some weeding may also be done, and crop rotations and interplanting are frequently observed. Using these techniques fallow periods on better soils may be no longer than the period of cultivation. Greater labor intensity may involve the use of manure, plowing, more intensive weeding, and either natural flooding or artificial irrigation.

A society using a given agricultural technique, which is unable or does not wish to gain access to additional land, will be forced to shorten fallow periods as the population increases. The resultant decrease in soil fertility leads to decreased yields which require that additional land be brought into cultivation to feed the population, thus decreasing fallow periods further. The downward spiral may be arrested only if there is an increase in mortality, emigration, or the use of more labor intensive techniques to maintain soil fertility. It is Mrs. Boserup's thesis that the last alternative has historically been the most common form of adaptation.

Although she is quite anxious to dissociate the range of techniques she describes from "...continuous production functions of the usual type...." (p. 26), such as marginal additions of labor input in the form of more careful weeding, for example, these techniques display all the properties which we usually associate with a neo-classical production function. This is especially true if the problem of heterogeneous capital goods is avoided by considering the very long-run nature of changes in productive techniques and by recognizing that the construction,

maintenance, and repair of capital equipment, such as ploughs, hoes, and irrigation systems, is a continuing and very labor intensive process which, for our purposes, may be regarded as a labor input. With little education and limited skill requirements, labor may be presumed to be homogeneous, though some division of labor usually exists between men, women, and children. Differences in the quality of cultivable land, the other input, are probably more important, but, within a given region, may not be too great. Furthermore, as A.T. Grove has observed, differences in soil conditions appear to be much less important for production decisions where population densities are relatively low--the range with which we are chiefly concerned. Output is generally far from homogeneous, and this is an important factor which Mrs. Boserup neglects. As long as the production function is meant to apply to a given region, however, variations in the composition of output are somewhat less. Furthermore, as will be seen in the next section, it is possible to adapt her analysis to the case where any number of crops are grown.

The production function that Mrs. Boserup describes is continuous since numerous minor adjustments can be made in the length of fallow periods, the amount of bush burned, the amount of manure applied, etc. The condition of reversibility is also satisfied. There are many instances of societies reverting to extensive techniques used previously in their history when confronted with a decrease in population density (see Boserup, pp. 62, 63).

Most important is her crucial hypothesis that, with labor input measured in manhours, as the amount of land per person decreases the amount of labor per worker can and must increase to produce a given level of output. Considerable evidence is presented to show that the variation in the time spent farming is very large. Even peak season labor inputs are not great under long-fallow systems of cultivation--perhaps four to six hours a day. Furthermore, a number of days are spent in other seasons without doing agricultural work of any kind. As fallow periods are shortened peak season demands for labor increase, but there are long periods when labor requirements are minimal. The use of annual cropping techniques, and especially the growing of more than one crop per year on the same land, makes much fuller use of labor throughout the year (see Boserup, pp. 46-53).

What Mrs. Boserup is describing is a movement along and not a shift of the production function. Although knowledge of techniques other than that being used by a particular society at a given time may not be perfect, it is seldom absent altogether. There is abundant evidence of contact between societies using different means of acquiring food.¹ Little incentive exists to intensify farming, however, as long as less work is required where more extensive techniques can be employed. It is only as population density increases that more intensive techniques must, of necessity, be used.

Admittedly, technological progress has occurred slowly over centuries in pre-industrial societies. The development of wet rice farming in Asia appears to be one such innovation. The application of this technology, under certain environmental conditions where elaborate irrigation systems

have not had to be constructed and maintained, probably resulted in an increased labor productivity even with less land per person. But as population expanded in these areas, techniques such as transplanting, though requiring more labor per capita, had to be devised to increase yields sufficiently to provide for subsistence (see Pelzer and Tun Wai). The initial shift of the agricultural production function, in other words, was later followed by a movement along the function. For the most part, however, a rapid rate of sustained technological progress, increasing the productivity of both labor and land, has occurred only since the introduction of manufactured inputs, such as steel plows and chemical fertilizers, and the use of scientific methods of experimentation in agriculture. Most changes in agricultural technique have been movements along, not shifts of, the production function.

Mrs. Boserup is concerned primarily with food production for survival and devotes little attention to commercialized agriculture.² An assumption implicit in her discussion is that, once subsistence requirements are met, no further increase in welfare is gained by producing and consuming more food. Instead, people seek to minimize the time they spend in agricultural work, devoting the remainder to leisure or non-agricultural activities. Given the production function, the amount of cultivable land per person, and the per capita food requirements, then, the number of manhours worked per person is uniquely determined.

There are a number of objections to this formulation, some of which are discussed by Mrs. Boserup. It is not clear, for example, why, even

in the absence of markets, there will not be some surplus produced as payment for the use of land where its scarcity prevails and systems of social and economic stratification exist. When there are opportunities for local or long distance trade, the amount of time spent in agricultural activities is also likely to be affected. Secondly, a utility function which includes only leisure is too restrictive. Finally, the imposition of a fixed land constraint is arbitrary and, in areas in which not all cultivable land is used for agriculture, unrealistic. Much of the land between settlements in sparsely populated regions, for example, is used only for hunting or gathering wild products and is freely available for cultivation.

II. The Land-Surplus Village Economy

It is assumed in the following analysis that the population of a region is concentrated in a number of nucleated villages from which farmers go to work in the surrounding fields. This is not the only possible pattern of rural settlement, dispersed farm homesteads being an alternative, but it is a very common one in the less-developed world. Where population densities are very low, villages tend to be small in size and widely spaced, their precise locations determined by fortuitous circumstances such as proximity to sources of water. As the population of such a village grows several things may happen. If the social, political or military forces which cause the members of the village to live together are very strong, the village remains concentrated and farmers have to walk increasingly longer distances to bring new land under cultivation. If these forces are

weak, however, the village may become dispersed, leaving each farmer in close proximity to his fields, or it may remain concentrated, but small, as younger members move away to find new land in surrounding regions. In either case there is a point at which the disadvantages of moving from the village center are compensated for by the advantages of being close to a larger area of unclaimed land. At first these new settlements may be temporary, but ultimately they form the nuclei of new villages.

With no limit to the land available for cultivation, its only cost is the time required by villagers to go to and from their fields over the course of a farming cycle. This is a function of the average distance of those fields from the center of the village and of the number of trips made. The latter depends, in part, on the number of hours worked since there is a limit to the daylight hours available each day. It also depends on the technique, which may require periodic visits to the fields even if little work is required during certain of these. This is true, for example, of the necessity of protecting crops from birds and animals at certain times of the year. Over the range of population densities with which we are concerned, much of the increase in labor takes place by increasing the number of hours worked on each trip rather than by increasing the number of trips.³

To simplify the analysis it is assumed that the time t required for each villager to travel to and from his fields is related only to the average distance of the fields from the village center.⁴ This average, with the distance from each plot of land to the center of the village weighted by the area of the plot, is equal to $\frac{2}{3} R$ where R is the radius of the total

land area A , including fallow, used by the village.⁵ The total distance which must be travelled, then, is $\frac{4}{3} Rk$, where k is the number of trips which have to be made over the farming cycle and is assumed to be invariant for a given crop. If it is assumed that the speed at which the farmer travels is some constant times the inverse of the distance he must travel,⁶

$$(1) \quad \frac{\frac{4}{3} Rk}{t} = \gamma, \quad \frac{1}{\frac{4}{3} Rk}; \quad t = \frac{16}{9\gamma} k^2 R^2 = \gamma R^2.$$

Since $A = \pi R^2$,

$$(2) \quad t = \frac{\gamma A}{\pi} = \frac{\gamma N}{\pi} a,$$

where N is the size of the village population, and a is the amount of land used by each person.

It is assumed that the utility functions of all persons in the village are identical, and decisions are made by the village collectively which treat all individuals in the same manner. All farmers have equal access to land, work the same number of hours, and employ the same technique.⁷

We define per capita leisure s rather broadly to include all the time left over from a fixed number of hours $\bar{y}$ after subtracting agricultural labor ℓ and travel time t .⁸ At first it is assumed that the village seeks to maximize s subject to the constraint that per capita agricultural output x , supposed initially to be homogeneous, must equal the subsistence standard $\bar{x}$. The production function described in the previous section is represented by $x(\ell, a)$. We assume that $x_\ell, x_a, x_{a\ell} > 0$ and $x_{\ell\ell}, x_{aa} < 0$, where subscripts

denote first- and second-order partial derivatives.

Forming the Lagrangean expression $s(\bar{y} - \ell - \frac{\gamma N}{\Pi} a) - \lambda(\bar{x} - x(\ell, a))$ and setting the partial derivatives of $\hat{L}$ and a equal to zero, the following first-order conditions are obtained:

$$(3) \quad -1 + \lambda x_{\ell} = 0$$

$$(4) \quad -\frac{\gamma N}{\Pi} + \lambda x_a = 0$$

$$(5) \quad x(\ell, a) - \bar{x} = 0$$

Equations (3) and (4) give the equilibrium condition

$$(6) \quad \frac{x_a}{x_{\ell}} = \frac{\gamma N}{\Pi}$$

This relationship is shown diagrammatically in Figure 1. The equation $\bar{y} = s + \ell + \frac{\gamma N}{\Pi} a$ is that of a series of straight lines, one for each value of s . In Figure 1 DG is such a line corresponding to DF of leisure, given the total time available OF. The slope of this line, $-\frac{da}{d\ell}$, is equal to minus the reciprocal of $\frac{\gamma N}{\Pi}$, the price of land in terms of time. The tangency at point E of DG and the isoquant corresponding to $\bar{x}$ represents the equilibrium condition of equation (6). In equilibrium OC units of labor are combined with OB units of land, requiring CD units of travel time.⁹

If equations (3) - (5) are differentiated totally,

$$(7) \quad \begin{bmatrix} \lambda x_{\ell\ell} & \lambda x_{\ell a} & x_{\ell} \\ \lambda x_{a\ell} & \lambda x_{aa} & x_a \\ x_{\ell} & x_a & 0 \end{bmatrix} \begin{bmatrix} d\ell \\ da \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ + \frac{\gamma}{\Pi} dN \\ 0 \end{bmatrix}$$

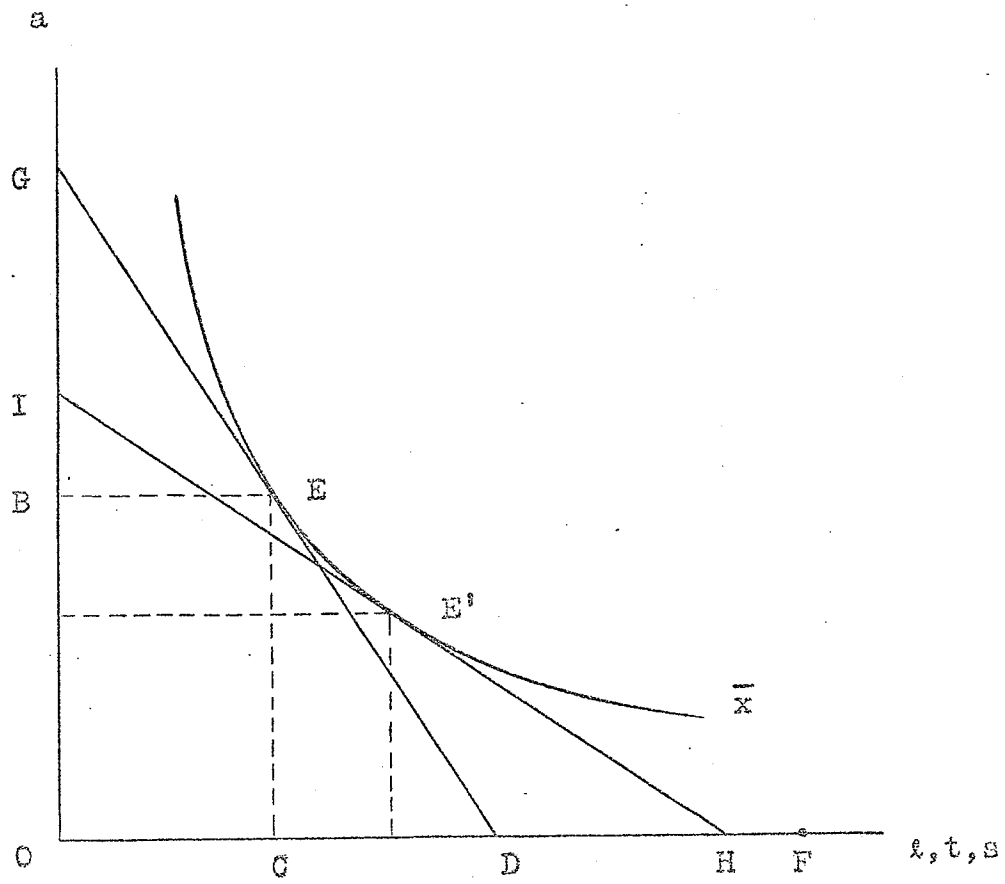


Figure 1

The effect of a change in population N on ℓ and a is given by applying Cramer's rule

$$(8) \quad \frac{d\ell}{dN} = + \frac{\frac{\gamma}{\Pi} \bar{x}_a \bar{x}_\ell}{|D|} > 0$$

$$(9) \quad \frac{da}{dN} = - \frac{\frac{\gamma}{\Pi} \bar{x}_\ell^2}{|D|} < 0,$$

where $|D|$ is the determinant of the system of equations (7). The effect of increasing N is to change the price of land in terms of time and to cause the line DG in Figure 1 to be rotated about the given isoquant ($x = \bar{x}$) to HI , establishing a new equilibrium at E' .

From equations (8) and (9), ℓ increases and a decreases as N increases. What is the effect on the total area A ? If the elasticity of substitution ϵ between ℓ and a is defined as

$$(10) \quad \epsilon = \frac{d(\ell/a)}{\ell/a} \div \frac{d(x_a/x_\ell)}{x_a/x_\ell},$$

it can be shown that, as long as equation (6) is satisfied,

$$(11) \quad \frac{dA/A}{dN/N} = \frac{d\ell/\ell}{dN/N} - \epsilon + 1.$$

Since $\frac{d\ell}{dN} > 0$, $\frac{dA}{dN} > 0$ if $\epsilon \leq 1$. If $\epsilon > 1$, $\frac{dA}{dN}$ may be less than, equal to, or greater than zero. Since $t = \frac{\gamma N}{\Pi} \frac{A}{N}$, the sign of $\frac{dt}{dN}$ will depend on the sign of $\frac{dA}{dN}$. Furthermore,

$$(12) \quad \frac{ds}{dN} = - \frac{d\ell}{dN} - \frac{\gamma}{\Pi} (a + N \frac{da}{dN}),$$

and, by substituting equations (6), (8), and (9) into (12), we see that $\frac{ds}{dN}$ is always negative.

The transition from a purely subsistence economy to one in which most production is for commercial purposes is probably a gradual process. In colonial Africa it was frequently initiated by the imposition, on the part of the colonial authorities, of production quotas or taxes payable only in currency. Later the target income desired for the payment of taxes might have been enlarged to include a bride price or the cost of some particular commodity. Ultimately, the expansion of demand to include a full range of goods and services originating outside the village implies the development of a utility function which includes not only leisure but also real income.

It is possible to analyse each of these cases using simple extensions of the model. The enlargement of output due to the imposition of a quota is equivalent to an increase in $\bar{x}$. A target income might be acquired by selling a surplus of agricultural products, in which case the constraint becomes

$$(13) \quad \bar{m} = P(x(\ell, a) - \bar{x}),$$

where $\bar{m}$ is the real value of the target income and P is the price ratio at which farm output may be exchanged for goods and services originating outside the village.

With the development of fully commercialized agriculture the Lagrangian expression becomes $u(m, \bar{y} - \ell - \frac{\gamma N}{\Pi} a) - \lambda(m - Px(\ell, a))$. It is assumed that $u_m, u_s, u_{ms} > 0$ and $u_{mm}, u_{ss} < 0$. The first order conditions now are

$$(14) \quad -u_s + \lambda Px_\ell = 0$$

$$(15) \quad -\frac{\gamma N}{\Pi} u_s + \lambda Px_a = 0$$

$$(16) \quad u_m - \lambda = 0$$

$$(17) \quad Px(\ell, a) - m = 0$$

yielding the equilibrium conditions

$$(18) \quad \frac{x_a}{x_\ell} = \frac{\gamma N}{\Pi}$$

$$(19) \quad \frac{u_s}{u_m} = Px_\ell.$$

The first condition is the same as equation (6) where $x = \bar{x}$; the second condition states that the marginal rate of substitution between time and income in consumption must equal the marginal rate of substitution between time and income in production. The conditions are shown together diagrammatically in Figure 2. For any given value of $\frac{\gamma N}{\Pi}$, there exists an equilibrium level of output for each amount of time spent in leisure. One such output, multiplied by P , is denoted in the figure by point B which corresponds to DF units of leisure and FC units of real income. Varying the amount of leisure traces out the curve OE . Differentiating $m = Px(\ell, a)$ and $s = \bar{y} - \ell - \frac{\gamma N}{\Pi} a$,

$$(20) \quad \frac{dm}{ds} = - \frac{P(x_\ell d\ell + x_a da)}{d\ell + \frac{\gamma N}{\Pi} da}.$$

Since, in equilibrium, $x_a = \frac{\gamma N}{\Pi} x_\ell$, we can substitute for x_a in the numerator to obtain

$$(21) \quad \frac{dm}{ds} = - Px_\ell.$$

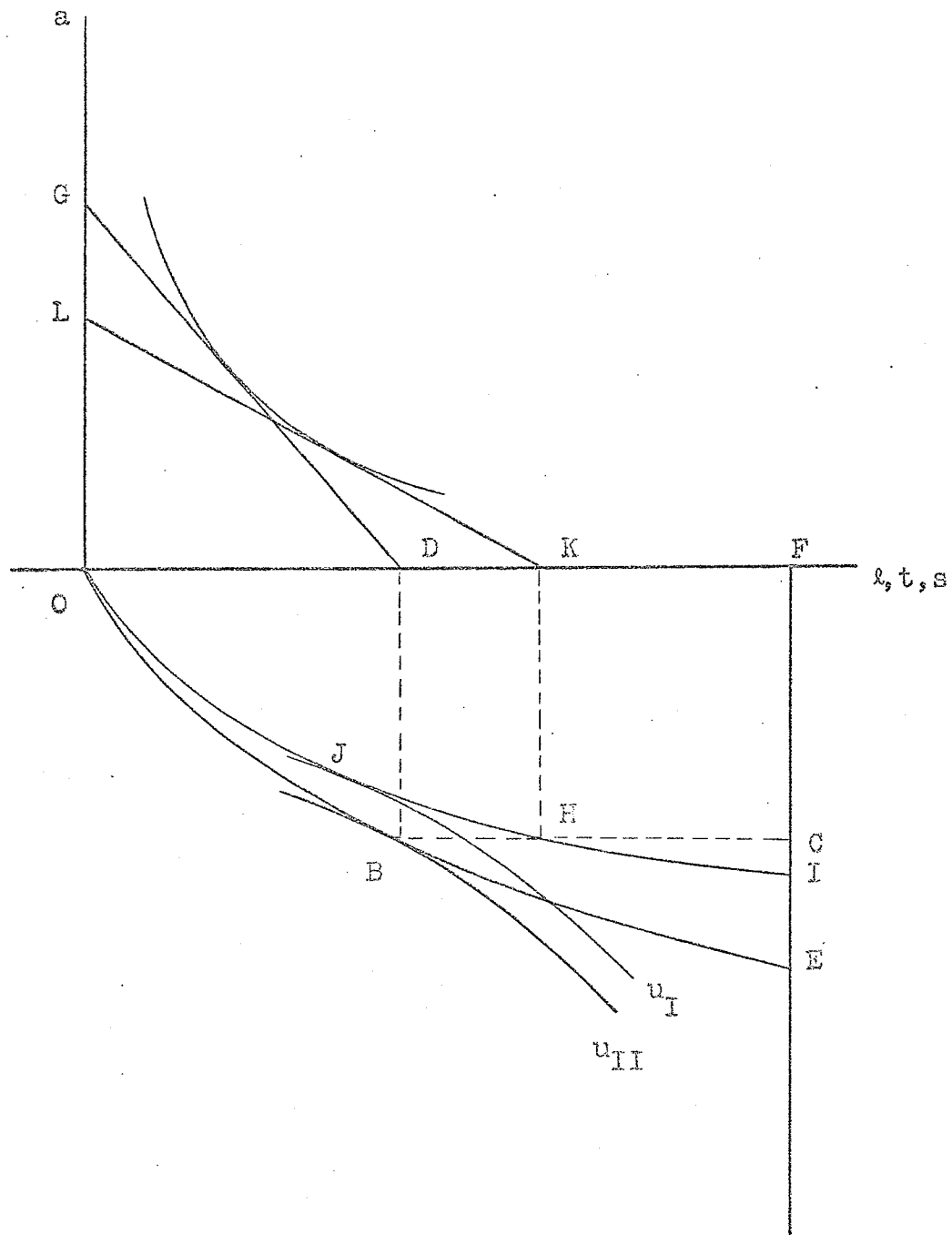


Figure 2

Equation (19) is represented by the tangency of OE with the highest indifference curve, corresponding to a level of utility u_{II} .

If the area of land is fixed in supply so that $da = 0$, equation (20) reduces directly to $\frac{dm}{ds} = -Px_{\ell}$. The difference between this situation and that represented by equation (21) is that, with the former, x_{ℓ} is the slope of the usual marginal product curve of labor, while, in the latter case, the marginal product of labor falls less rapidly as ℓ is increased because villagers are able to increase the total area farmed. This may be seen by examining the second derivative

$$(22) \quad \frac{d^2x}{ds^2} = - (x_{\ell\ell} \frac{d\ell}{ds} + x_{\ell a} \frac{da}{ds}).$$

If $\frac{da}{ds} = 0$, $\frac{d\ell}{ds} = -1$ and $\frac{d^2x}{ds^2} = x_{\ell\ell}$. But if $\frac{da}{ds} < 0$, the second term helps to offset the change in x_{ℓ} due to the first term. It is even possible that $\frac{d^2x}{ds^2} > 0$ if there are increasing returns to scale, i.e., a decrease in the average cost of output in terms of foregone leisure as output increases.¹⁰

It is useful at this point to see what happens to the opportunity locus OE when the village population changes. If the price line DG is rotated counterclockwise for an increase in N and kept tangent to the isoquant in Figure 2, leisure time is continually decreased for the given level of output as we move along BC. Point H is then determined, for example, by the price line KL. Similarly, any number of points could be located for different levels of output and price lines parallel to KL. These points all fall on the new opportunity locus OI. The point of tangency between the indifference curve U_I and OI is the new equilibrium J.

We can examine the effects of dN and dP by differentiating equations

(14) - (17) to obtain the following system of equations:

$$(23) \quad \begin{bmatrix} u_{ss} + \lambda P x_{\ell\ell} & \frac{\gamma N}{\Pi} u_{ss} + \lambda P x_{\ell a} & -u_{ms} & P x_{\ell} \\ \frac{\gamma N}{\Pi} u_{ss} + \lambda P x_{a\ell} & (\frac{\gamma N}{\Pi})^2 u_{ss} + \lambda P x_{aa} & -\frac{\gamma N}{\Pi} u_{ms} & P x_a \\ -u_{ms} & -\frac{\gamma N}{\Pi} u_{ms} & u_{mm} & -1 \\ P x_{\ell} & P x_a & -1 & 0 \end{bmatrix} \begin{bmatrix} d\ell \\ da \\ dm \\ d\lambda \end{bmatrix} = \begin{bmatrix} -\frac{\gamma a}{\Pi} u_{ss} dN \\ + \frac{\gamma}{\Pi} u_s dN - (\frac{\gamma}{\Pi})^2 N a u_{ss} dN \\ + \frac{\gamma a}{\Pi} u_{ms} dN \\ 0 \end{bmatrix} + \begin{bmatrix} -\lambda x_{\ell} dP \\ -\lambda x_a dP \\ 0 \\ -x dP \end{bmatrix}$$

The determinant of this system is negative with the exception of a term

$-u_m^2 P^2 (x_{\ell\ell} x_{aa} - x_{\ell a}^2)$. If $x_{\ell\ell} x_{aa} < x_{\ell a}^2$, a possibility if there are increasing returns to scale, the term is positive and, if very large relative to all the other terms of $|D|$, could make the determinant positive. For a stable equilibrium to exist the sign of $|D|$ must be negative, and we will assume that this is the case.

The effects of a change in the village population are given by

$$(24) \quad \frac{d\ell}{dN} = \frac{\frac{\gamma}{\Pi} u_s}{|D|} \left(-\frac{\gamma N}{\Pi} u_{ss} - 2 P x_a u_{ms} + P^2 x_{\ell a} x_{mm} + u_m P x_{\ell a} \right) + \frac{\frac{\gamma}{\Pi} P a u_{ms} u_{ss}}{|D|} \left(x_{aa} - \frac{\gamma N}{\Pi} x_{\ell a} \right) + \frac{\frac{\gamma}{\Pi} P^2 a u_m u_{sm}}{|D|} (x_a x_{\ell a} - x_{\ell} x_{aa})$$

$$\begin{aligned}
 (25) \quad \frac{da}{dN} &= - \frac{\frac{\gamma}{\Pi} u_s}{|D|} (u_{ss} - 2Px_{\ell} u_{ms} + P^2 x_{\ell}^2 u_{mm} + u_m P x_{\ell\ell}) \\
 &+ \frac{\frac{\gamma}{\Pi} P a u_m u_{ss}}{|D|} \left(\frac{\gamma N}{\Pi} x_{\ell\ell} - x_{a\ell} \right) \\
 &+ \frac{\frac{\gamma}{\Pi} a P^2 u_m u_{ms}}{|D|} (x_{\ell} x_{a\ell} - x_a x_{\ell\ell}) \\
 (26) \quad \frac{dm}{dN} &= - \frac{\frac{\gamma}{\Pi} P^2 u_s u_m}{|D|} (x_a x_{\ell\ell} - x_{\ell} x_{la}) \\
 &+ \frac{\frac{\gamma}{\Pi} P^2 a u_m u_{ss}}{|D|} \left(\frac{\gamma N}{\Pi} x_a x_{\ell\ell} - 2x_a x_{a\ell} + x_{\ell} x_{aa} \right) \\
 &+ \frac{\frac{\gamma}{\Pi} P^3 a u_m u_{ms}}{|D|} (2x_a x_{\ell} x_{a\ell} - x_a^2 x_{\ell\ell} - x_{\ell}^2 x_{aa}).
 \end{aligned}$$

The first term of each equation is the substitution effect resulting from the change in the implicit price of land, initially holding per capita land, labor and leisure constant. This term is negative for da/dN and dm/dN . It is usually positive for dl/dN but could be negative if x_{la} is very large, a situation which is unlikely given the stability condition assumed earlier. The last two terms show the effects of the change in leisure resulting from a change in population and are always negative.

These effects are illustrated in Figure 3. Given per capita labor and land at the initial equilibrium point M, an increase in N results in a decrease of leisure from DF to NF. To show the substitution effect, momentarily holding leisure constant, the total time available is increased by $FF' = DN$, and the indifference map is shifted to the right the same distance. The substitution effect, then, is represented by the movement from the initial equilibrium point B to point R where a shifted indifference

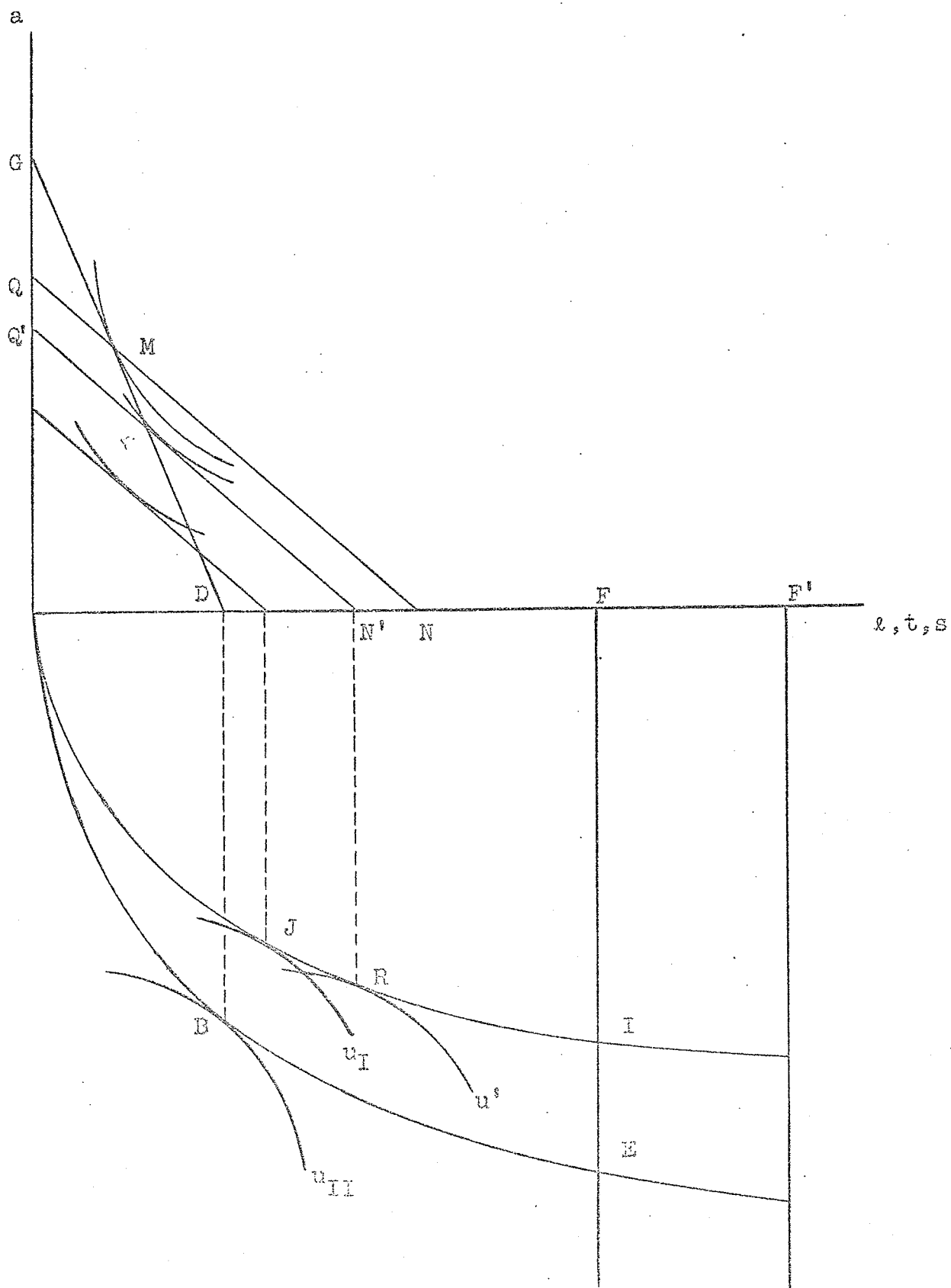


Figure 3

curve is tangent to the new opportunity locus OI. The movement along OI from R to J, the final equilibrium point, is the income effect. The effects of changing population on a , t , and s may be obtained by substituting equations (24) and (25) into (11) and (12). The results, as in the case of per capita labor input, depend on the relative importance of terms with opposite sign. It can be said, however, that, under the assumptions of the model, population growth results in a decrease in the amount of land used per farmer, despite the fact that free land is available away from the village, and a decrease of per capita agricultural production.

The effect of a change in P , perhaps due to an improvement in transportation to the village, is more straightforward. From the system of equations (23)

$$(27) \quad \frac{d\ell}{dP} = \frac{Pxu_m}{|D|} (Pu_{mm}(x_{\ell}x_{aa} - x_a x_{\ell a}) + u_{ms}(\frac{\gamma N}{\Pi} x_{\ell a} - x_{aa})) \\ + \frac{Pu_m^2}{|D|} (x_{\ell}x_{aa} - x_a x_{\ell a})$$

$$(28) \quad \frac{da}{dP} = -\frac{Pxu_m}{|D|} (Pu_{mm}(x_a x_{\ell\ell} - x_{\ell}x_{a\ell}) + u_{ms}(x_{a\ell} - \frac{\gamma N}{\Pi} x_{\ell\ell})) \\ + \frac{Pu_m^2}{|D|} (x_a x_{\ell\ell} - x_{\ell}x_{a\ell}).$$

In both cases, the income effect, or first term, is negative and the substitution effect is positive. There is by now substantial evidence that where surplus land is available, peasant farmers have responded positively to price changes.¹¹ Assuming that the substitution effect dominates the income effect, it is possible to compare the results shown by our model with the situation in which there is an absolute land constraint.

These two situations are depicted in Figure 4. The opportunity locus with land still available beyond the village is the curve OE. Under the alternative assumption it may be assumed that the limits to village areal expansion are reached at point B, and, to the right of that point, output is given by the total product curve of labor with land held constant. This curve, BG, lies everywhere inside of BE from equation (22). To simplify the diagram point B has also been chosen as the initial equilibrium, but this assumption is not essential to the proof.

As a result of the increase in P both curves are shifted to OC and OH. The indifference curves are drawn so that the substitution effect is greater than the income effect, and thus the new equilibrium points, I and J, lie to the right of point B. If $\left(\frac{dx}{dP}\right)_{da} > 0 \leq \left(\frac{dx}{dP}\right)_{da} = 0$, then J must be located at, or to the right of, point K along OH. The slope of the indifference curve passing through K is equal to $-\frac{u_s}{u_m}$. As we move from K to I this slope will decrease algebraically since $u_{ss} < 0$ and $u_{ms} > 0$. But if $\left(\frac{u_s}{u_m}\right)_K > \left(\frac{u_s}{u_m}\right)_I$, neither K nor any point along OH to the right of K can be a point of tangency since the slope of OH at K must be less than the slope of OC at I. Therefore, $\left(\frac{dx}{dP}\right)_{da} > 0 > \left(\frac{dx}{dP}\right)_{da} = 0$.

There is one extension of this model which is of particular interest.¹² So far it has been assumed that there is one homogeneous crop and that a single technique is employed at any given time. To conserve labor and travel time, however, several different techniques may be employed simultaneously, either for the same crop or for a variety of crops.¹³ Assume there are n

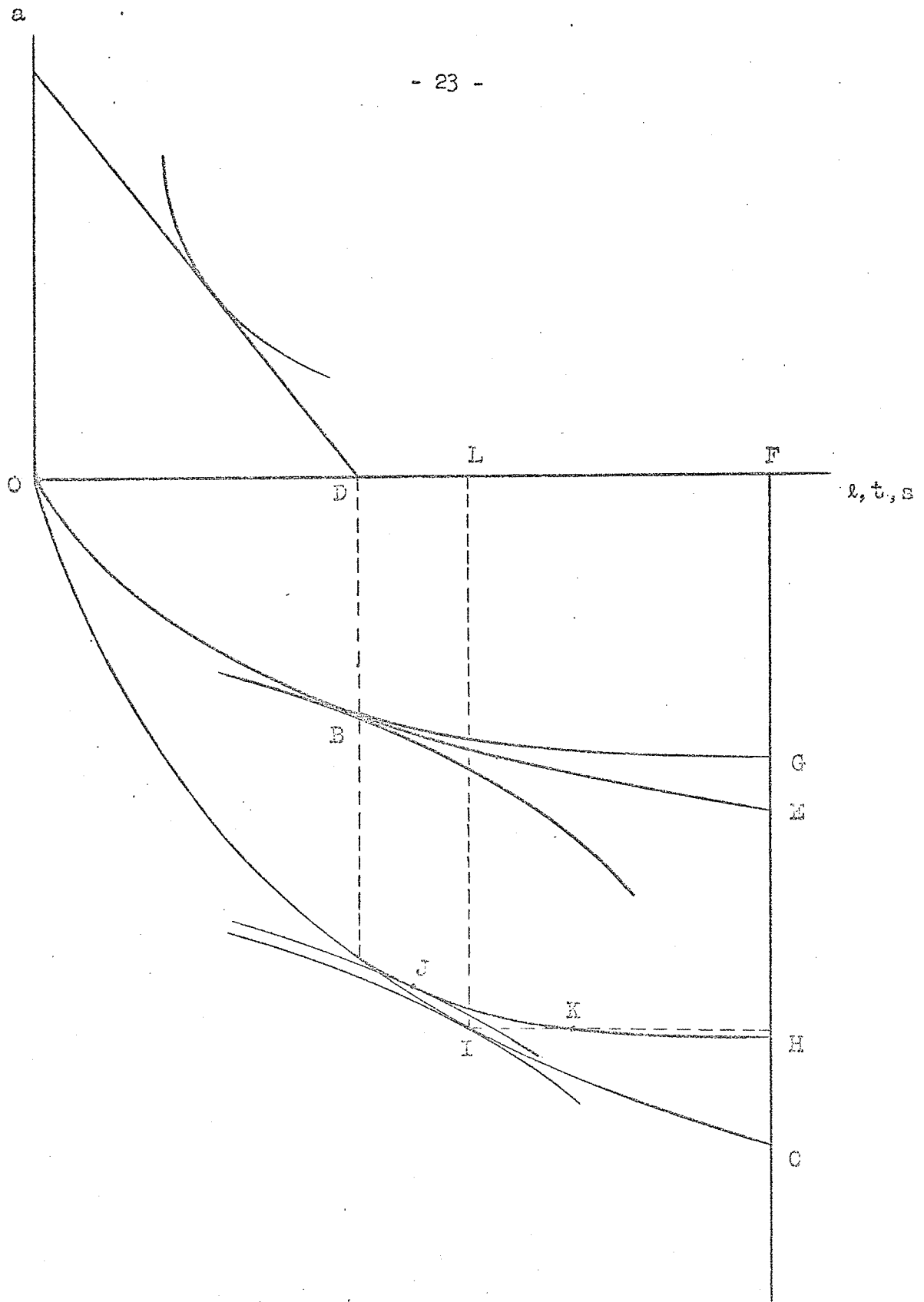


Figure 4

crops or techniques. The crops are sold commercially at a set of relative prices $P_1, P_2, \dots, P_n$. Where more than one technique is employed for a given crop, several of these prices may be identical. Each crop is grown on a plot of land, the outer border of which is a distance R_i from the village center. The time required over the farming cycle for each farmer to travel this distance and return is assumed to be $t_i = \sigma_i R_i^2$, consistent with the assumptions made previously section.¹⁴ The total area of land which includes all cultivated plots and fallow at this distance from the village center is $A_i = \pi(R_i^2 - R_{i-1}^2)$, the width of each circular ring being related to the indivisibilities associated with each crop or technique.¹⁵ The total time required to travel to all plots is given by

$$(29) \quad t = t_1 + t_2 + \dots + t_n \\ = \frac{N}{\pi} ((\sigma_1 + \sigma_2 + \dots + \sigma_n) a_1 + (\sigma_2 + \sigma_3 + \dots + \sigma_n) a_2 + \dots + \sigma_n a_n).$$

Forming the Lagrangean expression

$$u(m, \bar{y} - \sum_{i=1}^n \ell_i - \frac{N}{\pi} \sum_{i=1}^n \left(\sum_{j=i}^n \sigma_j \right) a_i) - \lambda (m - \sum_{i=1}^n P_i x_i(\ell_i, a_i)), \\ i = 1, 2, \dots, n$$

the first order conditions are

$$(30) \quad -u_s + \lambda P_i x_{\ell_i} = 0, \quad i = 1, 2, \dots, n$$

$$(31) \quad -\frac{N}{\pi} \left(\sum_{j=i}^n \sigma_j \right) u_s + \lambda P_i x_{a_i} = 0, \quad i = 1, 2, \dots, n$$

$$(32) \quad u_m - \lambda = 0$$

$$(33) \quad \sum_{i=1}^n P_i x_i(\ell_i, a_i) - m = 0, \quad i = 1, 2, \dots, n.$$

These yield the following equilibrium conditions

$$(34) \quad P_1 x_{\ell_1} = P_2 x_{\ell_2} = \dots = P_n x_{\ell_n} = u_s / u_m$$

$$(35) \quad x_{a_i} / x_{\ell_i} = \frac{N}{\Pi} \left(\sum_{j=1}^n \sigma_j \right), \quad i = 1, 2, \dots, n.$$

The $2n + 1$ equations (33), (34), and (35) may be solved for the unknowns ℓ_i , a_i and m , given the ordering of crops and techniques used.

This is only a partial solution, however, since there are $n!$ different ways in which the various crops and techniques may be ordered. Finding the optimum order in which to place crops is a programming problem which will not be considered here. From equations (34) and (35), however, it appears that crops planted close to the village should be those which are relatively labor intensive and which require frequent visits to the fields. Farmers are able, in this way, to reduce both the frequency of their visits to more distant fields and the amount of land over which they must travel before reaching these fields where more extensive techniques can be employed.

The effects of population change are substantially the same as those found in the previous section, applied now to the amount of labor and land used in each concentric ring. Price changes may also be analysed, but here, the effects are only suggested for the case in which all production functions are strictly concave. From equations (34) and (35) an increase in the price of a given crop, P_i , will if the substitution effect dominates the income effect, result in an increase of both ℓ_i and a_i , driving down their marginal products, and a decrease of all other labor and land inputs,

causing their marginal products to rise. The effects on the output of each crop are immediately obvious, and those on leisure, the total land area devoted to each crop, and the amount of travel time required for each crop can be derived by methods analogous to those used previously.

III. Empirical Applications

The theoretical model just presented is partial and is only meant to suggest one element to be used in the construction of a more complete theory of peasant decision-making. Unfortunately, the type of data required to rigorously test the hypotheses derived from the model are difficult to find. There exists, however, a number of qualitative and some quantitative observations assembled by geographers, anthropologists, agronomists, and economists, which may be illuminated by and help to support the theory. Most of this evidence has been gathered during the postwar period and complements that already referred to by Mrs. Boserup.

The main problem associated with using much of this information to test the validity of the production function described in the first section has to do with the nature of the observations. Most of these apply to the productive techniques generally employed at a moment in time within a given limited area, there being very little time-series or detailed cross-section data at the village or individual homestead level. Although it is possible to make comparisons between regions, it is difficult to correct for climate and soil conditions which vary considerably. If we omit the more extreme of these conditions, however, we may roughly interpret in terms of our model the productive techniques and land utilization practices which exist across

a rather broad range of population densities and introduce occasionally specific evidence which supports more strongly the hypotheses formulated previously.¹⁶ The following discussion, it should be observed, concentrates on areas in which agricultural practices are of a "traditional" nature and in which the introduction of inputs from the industrial sector has not been important, at least until very recently.

The most extensive agricultural techniques of shifting cultivation are found where population densities are very low, generally less than 25 persons per square mile. Frequently, less than one percent of the land is under cultivation in any given year. Fallow rights usually revert to the community, and land is reallocated for cultivation at the end of the fallow period. Plots may be scattered throughout the village territory, but there is a tendency for them to be located close to the village or near footpaths and roads, where fallow periods are often shorter. Although there is variation in the size of villages and hamlets or in the extent to which these are replaced by isolated homesteads, population concentrations are never very large. Cash crops usually form a minor, if any, part of total production.

Shifting cultivation with long fallow periods is found extensively throughout Africa, especially central Africa, is the dominant form of agriculture in the outer islands of Indonesia, and is widely practiced in the hilly regions of Southeast Asia. It has been estimated that over 500,000 squatters practice shifting cultivation on new, unsettled lands of Latin America and that their number is growing rapidly (see Hopkins, p. 56).

In areas where population is concentrated in larger villages or where commercial agriculture is more important, greater value is attached to land closer to the village and a differentiation of land use is frequently observed. In the savannah regions of West Africa where population densities are between 50 to 150 persons per square mile it is common to find a system of concentric circular rings with an outer zone of shifting cultivation, an intermediate zone of bush fallow, and an inner area of relatively intensive annual cropping or kitchen gardens. In the bush fallow zone, where fallow periods are up to ten years, land boundaries are more clearly delineated than in the area of shifting cultivation, and plots, though communally owned, usually continue to be assigned to individual families during the fallow if regularly brought into cultivation. The same is also true of land devoted to annual cropping near the homes. As predicted by the analysis of multiple crops and techniques in the previous section, the productivity of land close to the village is increased by the application of manure and household refuse and by hoeing and weeding.

Even where a system of concentric rings is not as fully developed as in West Africa, the simultaneous existence of several techniques is very common. Kitchen gardens which receive household refuse and other soil-enriching inputs are very prevalent on land surrounding homes in Asia and Africa. Cash crops which require less care than food crops are usually planted on land farther away from the village. In the forest zone of West Africa, for example, tree crops grown on land beyond that devoted to food are produced using less intensive techniques, as may be seen from Table 1.

Table 1 - Shares of Agricultural Time and Land Devoted to Different Crops in the Southeast Region of the Ivory Coast

Crop	Time	Land	Time/Land
Coffee	.35	.46	.76
Cocoa	.13	.31	.42
Food	.52	.23	2.26

Source: Derived from data in Ivory Coast, Ministère du Plan, Région du Sud-Est; Etude Socio-Economique: L'Agriculture I, pp. 19, 65.

The Boserup hypothesis that long fallow techniques require less labor per unit of output than do the more intensive techniques required as population density increases is supported by many pieces of evidence. Allan found that tribes in Zambia which practice the long-fallow citemene system of cultivation consider the hoe systems of agriculture employed in more densely populated nearby areas to be too time consuming (see Allen, p. 113). Numerous instances have been cited where farmers in Africa have abandoned regions of high fertility, but restricted area, for cultivation on poorer, but more abundant, soils (see Morgan, p. 249). The squatters in Latin America, referred to earlier, originally came from areas where more labor intensive techniques are used but turned to extensive techniques in the presence of abundant land. Finally, the Boserup hypothesis is supported by the widespread use of multiple techniques the labor intensity of which varies inversely with the distance of plots from the village. If there were not a decrease in

labor per unit of output to compensate for the increased time required to travel to the more distant fields, it is difficult to imagine why these outer areas should be farmed using more extensive techniques since this must increase the distances traveled.

One of the more important hypotheses of the previous section is that, if the substitution effect dominates the income effect when there is a change in the relative price of agricultural output, the production response is greater when there is land available for expansion, i.e., $\left(\frac{dx}{dP}\right)da > 0 \geq \left(\frac{dx}{dP}\right)da = 0$. There is strong evidence that very rapid rates of growth of cash crop production have occurred historically in regions of abundant land under the stimulus of improved transportation or favorable marketing situations.¹⁷ Indeed, Hla Myint's concept of the "vent-for-surplus" is based on this experience. The existence of initially low population densities in these areas, furthermore, implies that extensive agricultural techniques were probably once employed. Consequently, these areas have not only had the advantage of surplus land but have also benefitted from low labor requirements for subsistence food production. Finally, the making of decisions within the traditional social structure without requiring the evolution of factor markets has facilitated the process of reallocating land and labor.¹⁸

Available evidence indicates that the rapid expansion of cash crops, where it has occurred in Africa, has been accompanied by a substantial enlargement of the total area farmed. That the time spent traveling to and from fields has increased correspondingly is suggested

by a marked increase in the number of temporary camps established away from existing villages (see, for example, Ivory Coast, p. 112). Labor inputs per person have also increased, the requirements of cash crops often being greatest at other than peak times for food crops (see Hans Ruthenberg, p. 340, and Ivory Coast, pp. 70-76). Responses from farmers in Western Nigeria indicate clearly that cocoa trees are planted up to the point where the additional revenue gained by further extending production no longer compensates for the increased labor and travel time required. In the past, when prices have been high for several years or as population has increased, farmers have expanded the areas planted to cocoa and have either traveled farther or have established camps which frequently become the sites of new villages (see Godwin Okurume, p. 3, 14).

Once the profitability of cash crop production is established, if suitable land remains available, there is likely to be immigration of people seeking employment or land and the creation of markets for these productive factors. The rate of expansion may then depend on how efficiently these markets develop. If the indigenous peoples have a high preference for leisure, are unwilling to move, and are reluctant to have land alienated to foreigners, cash crop production may be frustrated for some time. In most cases, however, where opportunities have been profitable, means have been found for their exploitation.¹⁹ In some cases production by immigrant peoples has ultimately been much more important than by those who originally inhabited the area.

Where population densities rise above about 150-200 persons per square mile or where cash crops are an important part of total production, fallow periods have to be shortened considerably. Differentiation of land use still exists, especially between permanently cultivated kitchen gardens and the outer fields where fallow techniques may continue to be employed, but there is greater pressure on the land. Individual land rights are more jealously guarded, and greater attention may be paid to local variations in soil fertility. The location of plots cultivated by the family becomes more haphazard. Rights to land use are related more to the previous history of clearing and cultivation than to criteria of efficiency and equity. Land which is advantageously located, is of better quality, or has been subjected to capital improvements such as clearing and the planting of tree crops may be sold by individuals.

As fallow periods are shortened, and the area devoted to permanent cultivation is extended under the influence of accelerating growth rates of population and cash crop production, there is frequently a rather critical period of adjustment. Rather than intensively farming areas of better soil, farmers may continue to practice less arduous fallow techniques on land which is not adequate to support them. If there is insufficient manure²⁰ and no renewal of the land from natural or artificial flooding, the failure to engage in other methods of conservation results in erosion and soil deterioration. Farmers may even decrease their production of cash crops if population growth begins to threaten their ability to satisfy subsistence needs.²¹

IV. Conclusions

The resources may exist in sparsely populated countries for very rapid rates of expansion of cash crop production, but the constraints to this type of growth are not well understood. Although land may appear abundant, climate and soil conditions may be such that only low levels of population density can be supported at a subsistence level without the²² introduction of modern technology. Where cash crops can be introduced and farmers are not yet fully employed, it is not always clear that the planting of these crops is best accomplished by local inhabitants, or whether immigration and land resettlement should be encouraged. The receptivity to innovation of indigenous peoples and potential immigrants, attitudes toward land and leisure, the size of villages, and the strength of forces promoting village concentration are factors which must be considered.

So, of course, are demand conditions related to local and world markets, domestic commercial networks, and transportation facilities. The diseconomies associated with the provision of infrastructure in sparsely populated rural areas may be an important impediment to growth. Policies aimed at minimizing rural-urban migration may not only relieve the burdens of exploding urban areas but also increase the social profitability of government expenditures outside the cities if agricultural techniques can be changed rapidly enough to absorb these additional people.

The previous analysis also has implications for government policy at the local level. Agricultural extension agents may find farmers

more receptive to techniques for improving soil productivity where population and cash crops are pressing on the ability of the land to provide sufficient food using fallow practices. John de Wilde (pp. 48, 49), in fact, has noted that "... residents committed to village life may respond to efforts to intensify agriculture on the comparatively limited land near the village even though overall population density is low in relationship to land."

Where local travel time appears to be an important constraint, government policies to assist in the purchase of bicycles and the construction of bicycle paths might have beneficial results. In areas where local inhabitants are reluctant to leave their villages to expand production beyond a certain perimeter, institutional arrangements for the registration and sale of land to outsiders should be encouraged.

Most important, there is a need for more research concerning the relationship between population density and farming practices. It is quite clear that agricultural techniques can be altered in most areas to provide for growing populations without the massive effort and high cost associated with attempts at complete agricultural modernization. The factors promoting or inhibiting changes in population density and farming methods, however, are not well understood. That the current situation is critical because of rapid decreases in the death rate in recent times is well known. What is perhaps less well known is that this crisis is an outgrowth of the rapid spread of cash crops as well as of population growth. The result has been enormous pressure requiring

changes in agricultural techniques which occurred historically only over the course of centuries. And because extensive methods of farming are deeply rooted in the sparsely populated regions of the world, the situation there is no less grave than where population densities are much higher.

Footnotes

¹Allan, for example, describes numerous contacts between hunting and gathering societies, pastoralists, and cultivators practicing a variety of farming methods.

²The lack of opportunities of many peasant farmers to sell agricultural products, because of either a dearth of transportation and commercial facilities for the sale of cash crops or an undeveloped internal market for foodstuffs, has been emphasized by numerous authors, including Gerald Helleiner, E.A.J. Johnson, John Mellor, and W. B. Morgan (1969a).

³Since only four to six hours of work a day are usually required during the busy season where systems of long fallow are employed, there is scope for increasing the length of the working day. Even if longer hours are required, this does not necessarily increase the number of trips since overnight camps may be established near the fields.

⁴As will be seen, this has the effect of making it more costly in terms of time to substitute land for labor than would be the case if it depended upon the amount of labor used over the farming cycle as well.

⁵This is derived by taking the double integral

$$\int_0^{2\pi} \int_0^R \rho(d\theta)d\rho / \pi R^2 = \frac{2\pi}{3} R^3 / \pi R^2 = \frac{2}{3} R,$$

where ρ is the distance of each incremental plot from the center, $d\rho$ is the length of the plot, and $\rho d\theta$ is the arc of a circle with ρ as its radius which forms the width of the incremental plot.

⁶Although somewhat arbitrary, this assumption is very useful in making the analysis manageable. It is not unreasonable, furthermore, since tools, materials, and harvested products often have to be carried by hand, necessitating rest stops along the way. Distances traveled to the farthest fields may be as much as five miles (see Morgan, 1969b, p. 301).

⁷This is consistent with an egalitarian type of tribal organization frequently found where land is abundant (see George Dalton).

⁸Stephen Hymer and Stephen Resnick have analyzed an agrarian economy in which the concept of leisure is extended to include such nonagricultural activities as food processing, housebuilding, recreation, and transportation. Since labor time is the only input assumed to be used in the production of these goods and services, however, and since we are not concerned with increases of labor productivity in this sector, we assume that welfare is a function of the inputs of time instead of the outputs resulting from its use outside of agriculture.

⁹In a more general formulation where $t = t(\ell, A, N)$, DG is not a straight line but may be either convex or concave. The equilibrium condition in this case becomes $\frac{x_a}{x_\ell} = \frac{t_a}{1 + t_\ell}$. If $t_a = \frac{YN}{\Pi}$, as above, and t_ℓ is positive, more land and less labor will be used than in the case where $t_\ell = 0$.

¹⁰For equilibrium to be stable in this case it is necessary that the curvature of OE be less than that of the indifference curve.

¹¹See, for example, summaries of some of this evidence by William Jones and Raj Krishna.

¹²The analysis, here, was inspired by Morgan's (1969b) description of concentric circular ring systems of agriculture in West Africa, which, in turn, owes much to the work of J. H. Von Thünen.

¹³Mrs. Boserup explores the likelihood of simultaneously using several techniques, but only as part of a dynamic process resulting from increases in population density, and not as a condition of static equilibrium.

¹⁴For purposes of mathematical convenience the farmer is assumed to travel this distance rather than the distance to the center of the plot, but the results are substantially the same in either case.

¹⁵The discontinuities between rings are not likely to be great, however, since intercropping and minor alterations of technique are common in many less-developed countries.

¹⁶A large part of this discussion is taken from Allan, Morgan (1969a), Pelzer, and M.B. Gleave and H.P. White, who have surveyed much of the relevant literature dealing with Africa and Southeast Asia. Specific reference is given to work not referred to by these authors.

¹⁷Among the countries which have achieved these high rates of growth during certain periods in the past are Burma, Ghana, Malaysia, Nigeria, South Vietnam, Thailand, and Uganda. Probably the most notable recent example is the Ivory Coast, which has sustained an average annual rate of growth of exports of agricultural and forest products since World War II of about 8%.

¹⁸Many of these circumstances, which have favored the expansion of peasant cash crop production, have actually served to impede the creation of large-scale plantations. Land is easily obtained in sparsely populated areas, but wages must be high to induce farmers to leave their villages where subsistence needs may be met with relatively little effort. Furthermore, the decentralized decision-making of peasant producers is probably more efficient than centralized decisions made by plantation management but implemented by an unskilled and undisciplined work force.

¹⁹The contrast between the relative ease with which markets for land may evolve in sparsely populated regions as compared to the reluctance that farmers in more densely populated areas have to selling or even renting their land may be seen by comparing works by Polly Hill, Michael Lipton and Mellor.

²⁰Allan refers to several tribes in East Africa which keep cattle the only economic function of which is to provide manure.

²¹Ruthenberg (pp. 333-35) has confirmed this for areas in Tanzania.

²²Recent evidences presented by Boris Maldant et al for the francophone countries of Africa, however, indicates that there is very little correlation between population density and the natural quality of soil and climate, at least for the range up to about 150 persons per square mile.

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