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LAND EXPANSION, LAND AUGMENTATION AND LAND SAVING

by

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Not all land is cultivated, and the proportion of the area under cultivation varies with time and across countries. The explanation of such differences calls for the introduction of two elements into the discussion, land quality and land-specific cost. In this discussion it is important to differentiate between expansion and contraction of cultivated area. The expansion often requires investment in reclamation, bush clearing, roads, communication or other infrastructure facilities. Such investments are largely of the nature of setup costs and once made, they do not affect decisions on the intensity of land utilization. On the other hand, there are costs which are incurred as a result of holding or cultivating the land, such as taxes. If the tax rate depends on land productivity, it affects the decisions on whether and to what extent to utilize the land.

In this paper we examine the effect of the various determinants of land size and the relationships between the size and the intensity at which land its cultivated. This basically brings us to examine the Ricardian extensive and intensive margins. The main determinants to be examined are factors affecting the profitability of agriculture, the resource constraints, the role of infrastructure and a tax on land. The discussion abstracts from all the institutional factors affecting farmers' behavior.

The model is developed in steps in order to evaluate the role played by the main pertinent variables. In each step the simplest version needed to make the point is presented. As indicated above, the cost of land may take different forms, affecting differently long-run and short-run decisions. We do not differentiate between them in the discussion, but the results can be interpreted according to the case of interest. To

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[1] The Hibbard Lecture, University of Wisconsin, Madison, October 24, 1997. It is based on Mundlak (forthcoming).

economize the discussion, we often refer to the cost as a tax, but this is a generic term to be interpreted according to the case at hand. The model assumes two factors of production, land and capital. The first version assumes agriculture to be a price taker, the second model assumes a capital constraint and the third model assumes an output constraint. These two versions provide the needed insight and background for the empirical analysis. This is then followed by bringing in three forms of technical change: neutral, land augmenting and capital augmenting. Table 2 summarizes the qualitative properties of the model. The discussion is static in nature, but it can be extended to take into account the implications of intertemporal considerations. The same also holds true for the addition of labor into the analysis.

Background

There is no agricultural production without land, yet it is well known that much of the growth in agricultural output in the post-war period has come from an increase in yields rather than from land expansion. Table 1 summarizes information on changes in outputs and inputs for a large number of countries which account for the majority of world production.[2] The median of the average growth rate of (partial) average land productivity was 1.8 percent during 1967-92. Nevertheless, the cultivated area expanded in spite of the decline in the real price of agriculture. The performance was not even, and there is great variability across countries in all variables. As for land, Figure 1 shows that 35 percent of the countries reduced their cultivated land while the others expanded it. In most countries, the output growth is a result of both land expansion and augmentation.

The growth in yields was instigated by changes in the available technology and in its gradual implementation. This in turn facilitated the increase in output through the use of inputs other than land. To emphasize the role of technology, we refer to the increase in

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[2] The information on the cross-country performance is based on Mundlak, Larson and Crego (1997) and Crego, Larson, Butzer and Mundlak (1997). The number of countries for which information was available on a given variable differs by variables.

the input-land ratio as land augmentation. Under constant technology, land augmentation is the same as an increase in the intensity of land use.

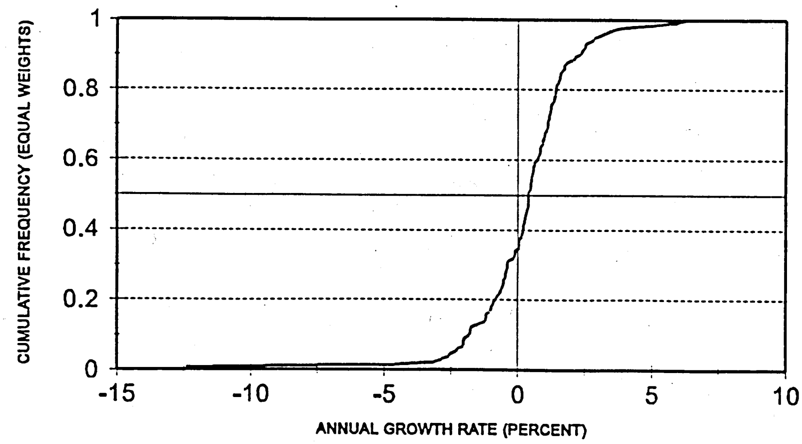

FIGURE 1 HARVESTED LAND
1967-1992 131 COUNTRIES

This raises the question of what determines the extent of the two effects, land augmentation and expansion, and why countries behave differently. Land augmentation is sometimes taken to be land saving. If this indeed were the case, the question is why agricultural land has not actually declined in all countries. The answer consists of two parts: first land augmentation is not a good definition of land saving, and second, we will see below that in most cases, the variables that cause augmentation increase land productivity and thereby increase the demand for agricultural land. This is the reason that the area under cultivation increased concomitantly with the improvement in its productivity.

The concept of factor-saving technical change, *a la* Hicks, should be related to the contribution of the factor to output, and this is measured by the factor share in output. The empirical discussion in the literature has suggested that the technical change has been land saving. This subject is not directly related to our analysis here, but it is related to the

For instance, Japan, as well as Korea and some other countries, subsidize heavily the price of rice and restrict the diversion of rice land to housing. As a result, the Japanese consumer pays a high price for both housing and rice. A recent study of the effect of modest liberalization of the rice import policy of Japan shows that some land will have to go out of production as a result of such a liberalization (Fujiki, 1993).

More generally, if agricultural prices affect the demand for land, a decline in prices due to the elimination of protection is expected to reduce the cultivated area. If for some reason this response is deemed undesirable, it can be neutralized by reducing taxes on land. This offers an important outlet for policy toward agriculture that is less distortive and more acceptable. Such a policy was applied recently in Argentina. The declining terms of trade in agriculture -- a result of the trends in the external terms of trade and of the appreciation of the domestic currency -- produced hardship in agriculture. To alleviate some of this hardship, the property taxes on land were reduced in 1993. It appears that a similar policy was also contemplated in the European Union. This tradeoff between prices and land taxes and its quantitative dimension comes out in a natural way from the following analysis.

The analysis provides a framework for the evaluation of a host of other important issues. Land is a specific factor to agriculture, and therefore rent is used as a measure of the terms of trade in agriculture (Mundlak, 1969). As such, it provides a measure of welfare changes caused by changes in the economic environment. This gives an economic meaning to the examination of the factor share of land and to the estimates of land elasticity in empirical production functions. This in turn provides a meaningful measure for the discussion of the changing role of land in modern agriculture.

Initial Specification

In this paper we deal with a deterministic world. Issues related to uncertainty are dealt with by Chavas (1993). The starting point is the model used by Lucas (1978) to analyze the distribution of firms. The quality of land, denoted by q, is assumed to be a continuous variable that takes on nonnegative values-- the higher is the value of q, the better is the land. Let A(q) be the available amount of land of quality q. To normalize the units of quality, we can refer to the distribution of land by quality, as illustrated in the upper panel of Figure 2.[3] The land used by agriculture, referred to as cultivated land, is all the land of quality $q \geq z$, where z is the marginal quality to be determined by the model. The area under cultivation is:

$$A = \int_z^{\infty} A(q)dq \ . \qquad (1)$$

The cultivated land, adjusted for quality is:

$$Q = \int_z^{\infty} qA(q)dq \ . \qquad (2)$$

To simplify the discussion, we assume that there is only one factor of production in addition to land, labeled as capital.[4] K(q) is the amount of capital allocated to quality q land, and k(q) is the capital-land ratio, k(q) = K(q)/A(q). Total capital used by agriculture is:

$$K = \int_z^{\infty} k(q)A(q)dq \ . \qquad (3)$$

The production function is expressed in terms of land measured in quality units, qA(q). Assuming constant returns to scale, the function for quality q land is

$$Y(q) = F[qA(q),K(q)] = A(q)qf(k(q)/q) \qquad (4)$$

where qf(k/q) is the output per unit of quality q land. By assumption, the function f(.) is

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[3] The distribution is given by $G(q) = \int_0^q A(x)dx \ / \int_0^{\infty} A(x)dx.$

[4] The production function can be viewed as a restricted profit function concentrated on land and capital.

twice differentiable, increasing and strictly concave, $f(0) = 0$, $f'(0) = \infty$, $f(\infty) = \infty$, $f'(\infty) = 0$. Total output is

$$Y = \int_z^\infty Y(q)dq = \int_z^\infty qf(k(q)/q)A(q)dq \quad . \tag{5}$$

The quantities, A, K and Y are functions of z and k(q). These in turn are determined by the state variables which vary with the specification of the model.

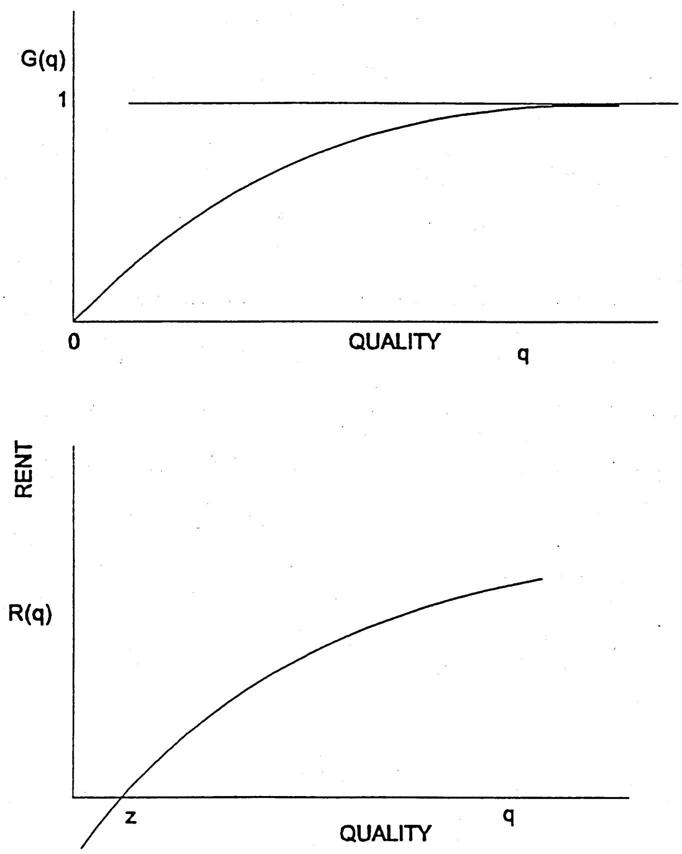

FIGURE 2 DISTRIBUTION OF LAND QUALITY

Let the user price of capital (rental rate) *be r,* the product price be p and c be the unit cost of using land, independent of its quality. The rent on quality q land is

$$R(q) = pqf[k(q)/q] - c - rk(q), \tag{6}$$

Differentiating R(q) with respect to q we obtain $R'(q)=[R(q)+c]/q>0$, implying that the rent increases monotonically with q. The marginal quality z is determined by $R(z)=0$. Hence for all $q>z$, $R(q)>0$, whereas the rent of the low quality land, defined by $q<z$, is negative and therefore that land is not cultivated. This is illustrated in the lower panel of Figure 2. The cost, c, plays an important role here because it forces low quality land out of production.[5] The economic problem is to determine what land to cultivate and at what level of intensity, measured by k(q). The different models considered below will endogenize some of the prices.

Agriculture as a price taker

In this model it is assumed that there is a perfectly elastic supply of capital at the rental rate r and a perfectly elastic product demand at price p and the cost c is independent of the land quality. In this specification, the level of intensity is determined independently of the extensive margin, z, because there is no resource or output constraint. Nevertheless, we will employ a general formulation that will serve us in the other cases. The formal presentation of the present problem is:

$$\max_{k(q),z} L(k(q),z) = \int_z^\infty [pqf(k(q)/q) - rk(q) - c]A(q)dq \tag{7}$$

The first order conditions for internal solution (FOC) are:

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[5] Under the assumption of $f'(0)=\infty$, if $c=0$ all the land will be cultivated or equivalently $z=0$, and for every $q>z$ there is $k(q)>0$ that maintains $r=f'(q)$. Thus, to account for uncultivated land it is necessary to have either $c>0$ or to change the assumption with respect to the production function. We take the first route.

$$L_1(.) = pf'[k(q)/q] - r = 0, \tag{8}$$

$$L_2(.) = pzf[k(z)/z] - c - rk(z) = 0 \tag{9}$$

where L_1 and L_2 are the partial derivatives with respect to k(q) and z respectively. In this model, the solution is recursive, we first solve for k(q) from (8). We insert the solution to equation (9) and determine z. This order can not be reversed because the value of z does not affect k(q). Keeping this in mind, the solution for z can be illustrated by drawing the graphs of the FOC in the (k,q) plane. Starting with equation (8), $f'(q)$ is a monotone function, its inverse exists and we can rewrite it as

$$k(q) = q\phi(r/p), \tag{10}$$

where $\phi(r/p)=f'^{-1}(r/p)$, $\phi'(r/p)<0$. The function $\phi(r/p$ indicates the optimal intensity for all q and it is shown in Figure 3. Given r/p, k(q) is a monotone increasing function of q, so that $k(q_A) < k(q_B)$ for $q_A < q_B$.

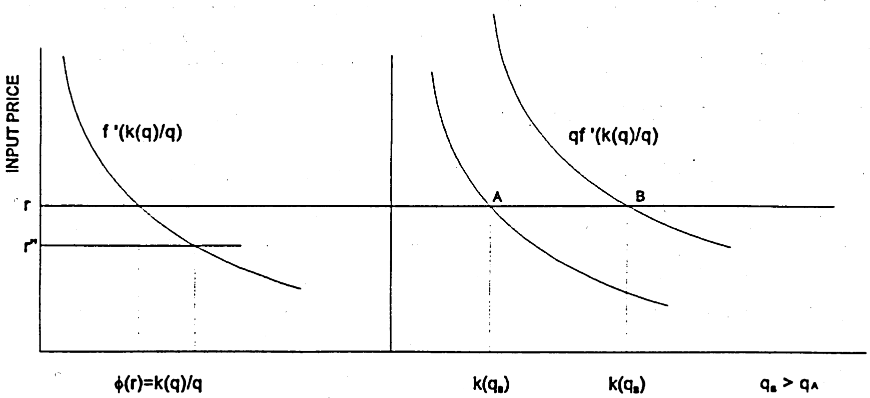

FIGURE 3 INPUT DEMAND

To determine z, we obtain the graph R(k,q)=0 which traces the combinations of k and q that result in zero rent. Using equation (9), we calculate the zero rent quality for any arbitrary k, any arbitrary k,

$$z(k) = \frac{rk}{pf(k/z)} + \frac{c}{pf(k/z)}. \tag{11}$$

This graph is drawn in Figure 4. As k increases the second term on the right hand side of equation (11) declines and the first term increases due to the concavity of f(k), so that the cost of capital increases linearly at the rate r but its marginal productivity decreases and at the limit, $k \to \infty$ implies $z \to \infty$. On the other hand, as k declines, the first term on the right hand side declines due to the concavity of f(k), whereas the second term increases at a faster rate and in the limit, $k \to 0$ implies $z \to \infty$. This means that to stay in production the quality must increase in order to compensate for the decline in output resulting from the decline in intensity of cultivation. Because resources are costly, producers are limited in their choice of k, and the optimal choice is given by equation (10). Thus, the intersection of the two functions, (10) and (11), provides the solution for z and k(z).

<u>The margins</u>

How do the margins respond to changes in the state variables r,p and c? To answer this question, we differentiate the first order conditions. Without a loss in generality we set p=1 so that r and c are measured in product units. When it is desirable to emphasize the role of p, we will switch notation and rewrite the real factor prices as r/p

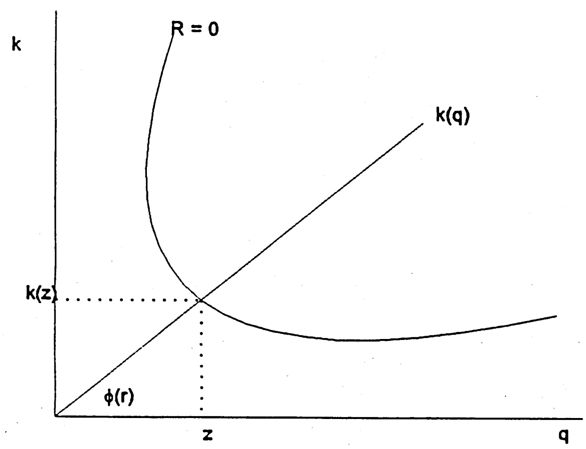

FIGURE 4 INTENSIVE AND EXTENSIVE MARGINS

and c/p. To simplify the notations when ambiguity does not arise, we use in what follows, $f(q) \equiv f(k(q)/q)$ and $f'(q) \equiv df(k(q)/q)/dk(q)$.

We differentiate equation (8), using equation (10), $f''(q)dk(q) = q\,dr$, (note that k(q) is independent of c), to obtain for $f''(q) \neq 0$:

$$\frac{1}{q}\frac{dk(q)}{dr} = \frac{1}{f''(q)} = \phi'(r/p) < 0 \qquad (12)$$

Thus equation (12) is simply the condition that the demand for an input declines with its real price. For any pair (y, x), we label the elasticity of y with respect to x as E(y,x) and rewrite equation (12) as elasticity:[6]

$$E(k(q),r) = \frac{d\ln k(q)}{d\ln r} \equiv -\sigma < 0$$

where $\sigma > 0$ is a measure of the degree of concavity of the production function. The stronger are the diminishing returns, the smaller is σ and therefore the weaker will be the relative response of capital intensity to a given change in r.

Turning to the marginal quality, differentiate (8) and rearrange, using the FOC:[7]

$$c/z\,dz = k(z)\,dr + dc \qquad (13)$$

It then follows that, $\partial z/\partial c = z/c > 0$ and $\partial z/\partial r = zk(z)/c > 0$. Writing the response as elasticities:

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[6] Note that $\sigma = -\frac{f'(q)/f''(q)}{k(q)/q}$.

[7]The total differentiation gives:

$$f(.)dz + f'(.)[dk(z) - \frac{k(z)}{z}dz] = \frac{r}{p}dk(z) + k(z)d\frac{r}{p} + d\frac{c}{p}$$

Collect terms, set p=1 and use the FOC to obtain (13).

$$E(z,c) = 1 \tag{14}$$

$$E(z,r) = \frac{rk(z)}{c} = \frac{S(k;z)}{S(c;z)}. \tag{15}$$

where S(k;q) = rk(q)/qf(q) and S(c;q) = c/qf(q) are the factor shares of capital and tax in the output of quality q land. At the margin, where q=z, the two shares add up to 1.

Equation (15) indicates that the marginal quality increases with r and c and therefore declines with p. This is illustrated in Figure 5. A decline in c moves the graph of equation (11) downward from R=0 to $\tilde{R}$=0, and the solution moves from B to C with lower z and k(z). However, as φ(r) is unchanged, k(q) remains constant for every q. On the other hand, a decline in r also moves the graph downward but it also changes φ(r) so that k(q) increases for every q. Consequently, the solution moves from B to N with lower z and higher k(q) for all admissible q.

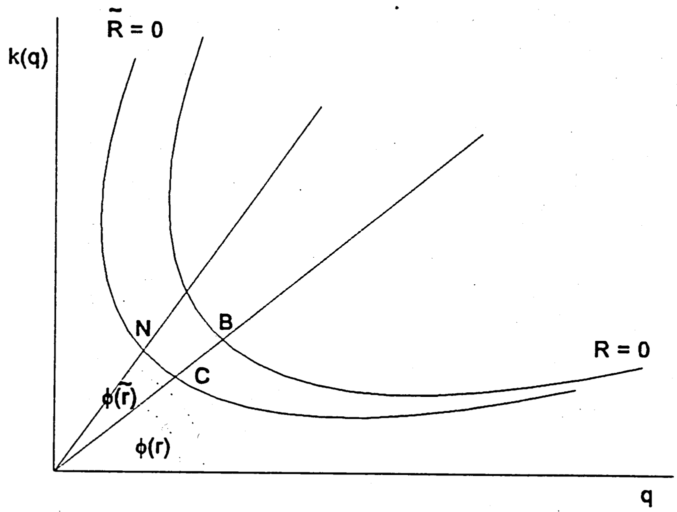

FIGURE 5 **MARGIN DISPLACEMENT**

<u>Property 1</u> An increase in r/p causes an increase in the marginal quality of land and a decline in the capital intensity. An increase in c/p increases the marginal quality land and does not affect the capital intensity.

This property is summarized in the first block of Table 2.

Total Agriculture

The size of cultivated land is determined by the marginal quality alone, and $\partial A/\partial z = -A(z) < 0$ or $E(A,z) = -zA(z)/A$. Combining this result with Property 1 we obtain the response function for cultivated land, $A(\underset{-}{r/p}, \underset{-}{c/p})$. The total use of capital increases with k(q) and, unlike k(q), it is also affected by z, $\partial K/\partial z = -K(z) < 0$. We combine this with property 1 to obtain, $K(\underset{-}{r/p}, \underset{-}{c/p})$. [8] We can write an aggregate production function $Y = F(K,A)$ where Y is defined in (5). Using the results on the response of K and A we summarize the supply function: $Y = F(\underset{-}{r/p}, \underset{-}{c/p})$. These results are summarized in the first block of Table 2.

Property 2 Cultivated area, total capital use and output are all declining with r/p and c/p.

Corollary In this model, a change in the economic environment (r/p and c) affects land and capital in the same direction, and specifically, a land augmenting shock is also land expanding.

The difference in the response of the two margins is in its magnitude. To compare the strength of the response to changes in r, we use equation (14) and write $E(A,c) = E(A,z)$. Also, $E(A,r) = E(A,z)E(z,r)$, using (15):

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[8] The slope of the demand for capital is $dK/dr = \partial K/\partial r + \partial K/\partial z\, \partial z/\partial r$ where the first term on the RHS is a substitution effect and the second term is the expansion effect, both are negative. The sign of the substitution effect follows from

$$\frac{\partial K}{\partial r} = \int_z^\infty \frac{\partial k(q)}{\partial r} A(q)dq = \phi'(r)Q < 0.$$

$$\frac{E(k(q),r)}{E(A,r)} = -\frac{\sigma}{E(A,z)}\frac{S(c;z)}{S(k;z)}$$

The ratio is inversely related to the thickness of the land margin as given by E(A,z),to the share of capital in the output of the marginal land, S(k;z), and it is positively related to the demand elasticity of capital.

Property 3 When the demand elasticity of capital is 'high', the change in capital, in response to a change in the rental rate, dominates that of land.

This is an extremely important result. Under the choice of technique framework, the demand elasticity for capital in agriculture, in the domain of coexistence of techniques, is likely to be very high and consequently most of the increase in output is coming from capital deepening.

Turning to rent, define the total rent to agriculture as R then,

$$R = \int_z^{\infty} R(q)A(q)dq = Y - rK - cA.$$

Invoke the envelope theorem, $\partial R/\partial r = -K < 0$, $\partial R/\partial c = -A < 0$. We write the result in terms of elasticities:

$$\begin{aligned} E(R,r) &= -\ S(K)/S(R) \\ E(R,c) &= -\ S(c)/S(R) \end{aligned} \qquad (16)$$

where S(K) = rK/Y, and S(c) = cA/Y respectively. As the shares S(K), S(c) and S(R) add up to 1, we can write:

$$E(R,r) + E(R,c) = [S(R) - 1]/S(R).$$

Property 4 The larger is the share of rent in output, the more robust is the rent to changes in the economic environment, represented here by r, c and p.

Resource constraint

In this model we replace the assumption that agriculture is a price taker in the market for capital goods with the assumption that capital is fixed at K and consequently, the economic problem is to allocate it to lands of different quality. The allocation decision is described by:

$$\max_{k(q),z,r} L(k(q),z,r) = \int_z^{\infty}[qf(k(q)/q)-c]A(q)dq - r[\int_z^{\infty}A(q)k(q)dq - K] \tag{17}$$

where r is the shadow price of capital, measured in units of output. The FOC are equations (8) and (9) above with p set at 1 and the resource constraint,

$$L_3(.) = \int_z^{\infty}A(q)k(q)dq - K = 0 \tag{18}$$

The solution for k(q) and z is similar to the first case. The difference is that now r is endogenous and therefore we can not solve for k(q) independently from the solution for z and r. With this qualification, the solution can be illustrated in terms of Figure 5.

To obtain the response of resource allocation to the state variables K and c, we differentiate the first order conditions. The derivative of the first of these conditions is given by equation (12) above and that of the second is given by equation (13). Finally, to differentiate equation (18), we use equations (10) and (7) to rewrite it,

$$\phi(r)Q = K \tag{19}$$

Hence, $\phi(r)dQ + \phi'(r)Qdr = dK$. Use equation (6) to write $dQ = -zA(z)dz$ and write the differential of equation (19) as

$$-\phi(r)zA(z)dz + \phi'(r)Qdr = dK \tag{20}$$

Write equations (13) and (20) in matrix notations:

$$\begin{bmatrix} c & -\phi(r)z^2 \\ -\phi(r)zA(z) & \phi'(r)Q \end{bmatrix} \begin{bmatrix} dz \\ dr \end{bmatrix} = \begin{bmatrix} zdc \\ dK \end{bmatrix} \tag{21}$$

The system is solved for dr and dz in terms of dK and dc. Label the matrix by M, and note that except for M_{11}, all elements of M are negative and therefore det M is negative as well. As $M_{11} = c$, we obtain

$$c(\det M)^{-1} = \partial r/\partial K < 0. \tag{22}$$

Equation (22) bridges the two models, and the qualitative results of the first model are preserved.

The Effect of Capital

An increase in K causes a reduction of r which in turn increases the level of intensity and the rent on all cultivated lands. Consequently, the rent on the marginal land becomes positive and the marginal quality declines. Leaving the details to note 1 in the appendix, we state:

Property 5 An increase in capital causes a decline in the marginal quality land and in the real rental rate, r/p, and an increase in capital intensity. As a result, cultivated land, output and total rent on land increase.

The strength of the response of A to K is proportional to the abundance of marginal land, measured by E(A,z), to the capital intensity of the technology as measured by the share of capital on the marginal land and to the response of r to changes in K as determined by the degree of concavity of the production function.

The elasticity E(z,r) in this model (A.1 in the Appendix) has the same appearance as that of equation (15) but it is important to note that in this model both z and r are endogenous and as such they vary only in response to changes in K or c. Thus, (A.1) is just a characterization of the changes in z and r along the path generated by a change in K with c held constant.

Effect of Tax

The main difference of this model from the first one is that under resource constraint a change in the tax affects the level of intensity. A rise in the tax rate causes a decline in the rent and thereby the marginal quality land is forced out of production. This frees capital to be distributed to the cultivated land and thus causes an increase in the intensity of capital and a decline in the rate of return. This can be seen by solving equation (21) to obtain $\partial z/\partial c>0$, $\partial r/\partial c<0$ and,

$$E(k(q),c) = E(k(q),r)E(r,c) > 0. \tag{23}$$

Qualitatively, the response of the size of the cultivated land is similar to that obtained in the first model:

$$E(A,c) = E(A,z)E(z,c) < 0. \tag{24}$$

When a unit of marginal land goes out of production, output declines by zf(z) and increases by reallocation of capital to the cultivated land by rk(z), the difference between these two terms is c, which is the net decline of output due to the increase in the tax. The total loss of output depends on the size of the margin. This result can be obtained formally by differentiating (7) with respect to z, using the optimal quantities of k(q),.

Property 6 An increase in the land real tax rate, c/p, causes an increase in the marginal quality land, a decline in the shadow rental rate, and a rise in capital intensity. As a result, cultivated land, output and total rent decline.

We thus see that taxing land is not costless and a decrease in the tax increases output. Any cost specific to land will have a similar effect to that of land tax. It is important to differentiate between a fixed set up cost and ongoing or variable cost. The first will affect the pace of reclamation of new land whereas the latter will affect the size of the land actually cultivated in a given year.

The results of this model are summarized in the second block of Table 2.

Output quota

In the foregoing discussion, product demand was taken to be perfectly elastic. We now analyze the other extreme case where the demand is perfectly inelastic and examine the changes in factor demand caused by a change in output. The analysis is related to a variety of subjects, most important, the differentiation between the substitution and expansion effects of a change in the economic environment on the demand for land. The substitution effect is relevant for the evaluation of the consequences of support programs with production quota.

When output is held fixed, the problem of optimal resource allocation is that of cost minimization:

$$\min_{k(q),z,p} L(k(q),z,p) = rK + cA - p(Y - Y^*) \tag{25}$$

where A, K and Y are defined in equations (5), (7) and (9) respectively. The Lagrange multiplier, p, is the marginal cost of producing Y^*. The interpretation is that when the demand is perfectly inelastic, the price is determined by the supply function. The FOC are:

$$L_1 \equiv \partial L(.)/\partial k(q) = r - pf'(q) = 0, \tag{26}$$

$$L_2 \equiv \partial L(.)/\partial z = pzf[k(z)/z] - c - rk(z) = 0 \tag{27}$$

$$L_3 \equiv Y^* - \int_z^\infty qf(k(q)/q)A(q)dq = 0 \tag{28}$$

Differentiate the FOC to obtain:

$$dr = pf''(q)/q \; dk(q) + f'(q) \; dp \tag{29}$$

$$c/z \; dz + zf(.) \; dp = k(z) \; dr + dc \; ^{10} \tag{30}$$

$$dY^* - (m/p) \; dr = -mr/p^2 \; dp - Y(z) \; dz, \; ^{11} \tag{31}$$

where $m \equiv Q\Phi'(r/p)r/p<0$. The system (30) and (31) can be written in matrix notation:

$$\begin{bmatrix} -mr/p^2 & -Y(z) \\ zf(z) & c/z \end{bmatrix} \begin{bmatrix} dp \\ dz \end{bmatrix} = \begin{bmatrix} 1 & -m/p & 0 \\ 0 & k(z) & 1 \end{bmatrix} \begin{bmatrix} dY^* \\ dr \\ dc \end{bmatrix} \tag{32}$$

-Y(z) is the only negative term in the above matrices. We can therefore sign the partial derivatives as follows:

$$\underset{- \; - \; +}{z(Y, r, c)}, \quad \underset{+ \; + \; +}{p(Y, r, c)} \tag{33}$$

We solve for dp from equation (32) and use equation (29) to solve for dk(q).

With these results we can now infer about the response of the rest of the system to a change in the economic environment. An increase in r causes a decline in k(q) and therefor z must decline in order to increase the cultivated land to fulfill the output quota. The final outcome is also a decline in K, because of the increase in A. Since k(q) is a function of r/p, a decline of k(q) when r increases implies that p increases by less than r, the reason is that capital is not the only input.

An increase in c causes an increase in z, a decline in A, and increase in K. Also, p increases, hence r/p declines and k(q) increases for all q. The rent decreases due to the increase in the tax on agriculture. Here again, like in the case of capital constraint, a land tax affects resource allocation.

In contrast to the case of unrestricted output, summarized in properties 11 and 12, the demand for land and capital under output quota move in opposite directions. This movement represents the substitution effect, or a movement along an isoquant of the aggregate production function. The expansion effect is in the same direction for the two inputs. An increase in Y causes a decline in z, an increase in A, an increase in p, a decline in r/p and increase in k(q) for all q and hence an increase in K. From this we infer that when output was unrestricted, the expansion effect generated by a change in the factor prices, dominated the substitution effect. To obtain the point where the two effects are equal, we can set dz=0 and solve equation (32), allowing output to change. This is assigned as an exercise.

The results are summarized in Property 7 and in the third block of Table 2.

<u>Property 7</u> Under output quota, the quality of the marginal land declines with r and increases with c. A change of either of these prices causes land and capital to move in opposite directions.

The Role of Prices and the Competitive Position of Agriculture

The foregoing analysis has repercussions for several attributes of cardinal importance for policy considerations. The nature and the strength of the response of agriculture to external or internal shocks is related to its competitive position, a concept we want to define explicitly.

<u>Definition</u>: The competitive position is measured by the factor share of land that comprises the agricultural-specific factor of production.

The higher is the factor share of land, the less is agriculture susceptible to shocks. It is important to emphasize that the measure does not speak of the competitive position of farmers. Farmers who operate on the margin of their profitability because of low ability or because of past decisions affecting their balance sheets may be wiped off by unfavorable shocks. However, the land remains in agriculture and will be acquired by others. Thus, unfavorable shocks will cause revaluation of assets, and sometimes severely, but the effect on output and resource utilization will be much milder.

The effect of shocks on agriculture can then be viewed at two levels, the effect on land and the effect on output. The effect on land is related to the effect on the rent of the marginal land. When the rent becomes negative, land is going out of production. The effect on output is analyzed in Mundlak (1996). What is relevant for our discussion is that the supply elasticity can be approximated by the expression:

$$\partial \ln Y / \partial \ln p = \mu/(1 - \mu) \tag{34}$$

where, for our purpose, μ is the sum of the factor shares of the variable inputs, which in our case is equal to the share of capital, and $1-\mu$ is the share of land. Thus, the higher is the share of land, the lower is the supply elasticity.

Technical Change and Land Expansion

We continue the discussion by considering three natural forms of technical change. We examine here the case in which agriculture is a price taker and thereby obtain the supply response under constant prices.

Neutral technical change

The production function is $\tau F(qA(q), K(q)) = \tau qA(q)f(k(q)/q)$. The role of the technology index τ is the same as the price p in the constant technology model considered above, and its results are immediately applicable. Specifically, neutral technical change causes the two margins to expand.

Land augmenting technical change

The production function is $F(\tau qA(q), K(\tau q)) = \tau qA(q)f(k(\tau q)/\tau q)$.
The optimization problem is:

$$\max_{k(\tau q),z} L(k(\tau q),z)) = \int_z^{\infty} [\tau q f(k(\tau q)/\tau q) - rk(\tau q) - c]A(q)dq \qquad (35)$$

The first order conditions are:

$$L_1 = f'(k(\tau q)/\tau q) - r = 0 \qquad (36)$$

$$L_2 = \tau z f(k(\tau z)/\tau z) - rk(\tau z) - c = 0. \qquad (37)$$

Differentiate L_1 and rearrange to obtain:

$$\frac{\partial k(\tau q)}{\partial \tau}\Big|_r = \frac{k(\tau q)}{\tau} > 0 \ . \qquad (38)$$

Differentiate L_2 and rearrange to obtain: $\frac{\partial z}{\partial \tau}\Big|_r = -\frac{z}{\tau} < 0$, or $E(z,\tau) = -1$. To interpret this result, differentiate,

$$\frac{\partial R(\tau q)}{\partial \tau} = \frac{R(\tau q) + c}{\tau} > 0. \qquad (39)$$

Hence, as τ increases, the rent increases for all q. Therefore the margin is moved and z declines.

Property 8 When agriculture is a price taker, land augmenting technical change causes the expansion of land, the capital-land ratio and total output.

Capital augmenting technical change

The production function is $F(qA(q), \tau K(q)) = qA(q)f(\tau k(q)/q)$.
The optimization problem is:

$$\max_{k(q),z} L(k(q),z)) = \int_z^{\infty} [qf(\tau k(q)/q) - rk(q) - c]A(q)dq$$

(40)

The first order conditions are:

$$L_1 = \tau f'(\tau k(q)/q) - r = 0 \tag{41}$$

$$L_2 = zf(\tau k(z)/z) - rk(z) - c = 0. \tag{42}$$

Differentiate L_1 and rearrange to obtain:

$$d\ln r = d\ln \tau + d\ln f'(.)$$

where

$$d\ln f'(.) = -\frac{1}{\sigma}\left(\frac{d\tau}{\tau} + \frac{dk(q)}{k(q)}\right) \quad \text{and} \quad \frac{1}{\sigma} = -\frac{f''(.)}{f'(.)}\frac{\tau k(q)}{q} > 0.$$

Combine the equations and set dr=0 to obtain:

$$\frac{d\ln k(q)}{d\ln \tau} = \sigma - 1 . \tag{43}$$

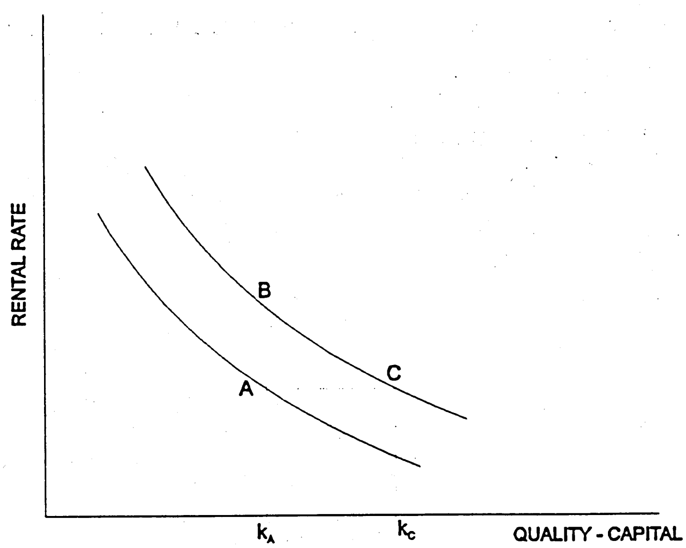

FIGURE 6 DEMAND FOR QUALITY- CAPITAL

We can interpret this result with the aid of Figure 6. The technical change has two effects. First, it shifts the marginal productivity of capital so that the initial point A, with quality-capital k_A, shifts to B. This shift disturbs the first order condition and to restore it, the quality capital increases to k_C that corresponds to Point C. The proportional change in the marginal productivity between A and B is $\hat{\tau}$, and the movement from C to B is along the curve whose elasticity in absolute value is σ. Thus the relative change of quality-capital between A and C is $\hat{\tau}\sigma$. The larger is the numerical value of this elasticity, the larger is the relative difference between k_C and k_A. Second, to translate the rate of change in quality-capital to that of physical capital we subtract $\hat{\tau}$. The new level of physical capital is the net outcome of these two effects as the above expression indicates. When the demand for capital is inelastic, the retraction dominates and the capital intensity declines, but this is not an interesting case empirically because it calls for the expansion of land and a decline in the capital-land ratio.

Next, differentiate $L_2(.)$ to obtain

$$E(z,\tau) = -\frac{S(k,z)}{S(c,z)} < 0. \tag{44}$$

The discussion is summarized by:

Property 9 When agriculture is a price taker, capital augmenting technical change reduces the marginal quality land and thereby increases the cultivated area. The corresponding change in capital intensity depends on the elasticity of capital demand; it increases (decreases) when the demand is elastic (inelastic).

Of the three cases of technical change analyzed here, this is the only case where the land expansion and augmentation can take different direction, but as indicated, it is not an interesting case from an empirical point of view.

On land saving

The foregoing discussion indicates that in general shocks that induce higher output also increase the demand for land. The question is whether the importance of land as a factor of production has declined. One measure of this is to look at the ratio of capital (or more generally, the aggregate input). This is the concept of land augmentation. This indeed has increased with time. However, this does not tell anything on the contribution of land to production. The natural measure for this is the factor share, or production elasticity, of land. A survey of empirical production functions (Mundlak, 1997) shows that in most country studies based on time series data, the elasticity of land is not negligible, regardless of the period of analysis. On the other hand, cross-country studies show zero, or very small, elasticities for land. This led authors to claim that land has lost importance in modern agriculture, (e.g. Kawagoe and Hayami, 1985, p.91).

In a world of heterogenous productivity, cross-country regressions do not identify a production function because the observation are generated by different production functions. This point has been discussed by Mundlak, Larson R. Butzer, (1997) who show that when state variables are introduced to account fro the differences in technology, including time and country dummies, the elasticity of land is substantial, around .40. For the same sample of countries, the between country regression gives a zero elasticity, in common with the results obtained in other studies. This shows that the techniques used by the more productive countries used techniques with higher input-land ratios (basically, higher capital-land ratios). However, with a given technology, and this goes for modern technology as well, the contribution of land to output is substantive. The finding is illustrated in Figure 7 where we draw production functions for three countries, which operate at points *a*, *b* and *c*. Country *a* is the poor country and applies the lowest capital-land ratio, whereas country *c* is the richest country. When the more productive techniques are capital intensive. Country *a* is also the least productive. The between country regression is based on a line that goes through points a,b and c and its intercept is zero, indicating a zero productivity for land. However, in each country, the marginal productivity of land is far from zero.

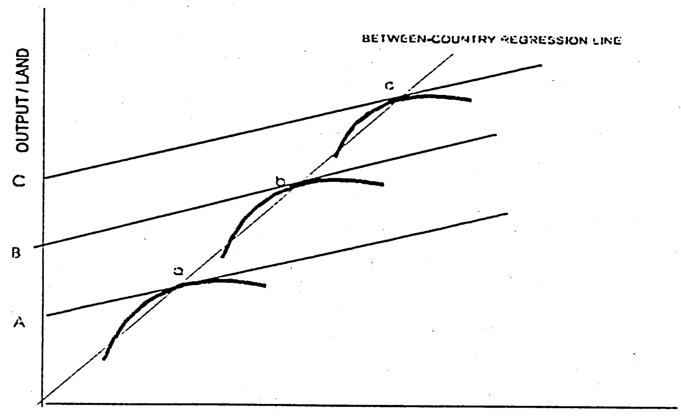

FIGURE 7 LAND PRODUCTIVITY
WITHIN AND BETWEEN COUNTRY ESTIMATES

It is always useful to check the results against all available information. The Global Trade Analysis Project (GTAP) reported factor shares of land and labor in agriculture for 1992 for 24 regions (Hertel, 1997). The data needed to compute factor shares are not available for all countries. The more available data are on labor costs, and these were used as a pivot to generate the other shares relying on “other sources” where available (op. cit., p.113). Mundlak, Larson and Butzer (1997) applied the appropriate regional data to the 37 sample countries and reported the empirical distributions. The median value for land is 0.25. This is conveniently close to the within estimates and is conspicuously far away from the between-country estimates. We take it as an independent support for our interpretation.

Empirical analysis - land expansion in Thailand

To apply the foregoing analysis to the data, we have to differentiate between short term fluctuations in land use and between changes of a more permanent nature. This is not an easy task because of lack of the necessary data for such an analysis. Alternatively, we can examine a situation where the permanent expansion was dominating, such as Thailand. It was examined in Mundlak (1993) and we summarize here some results of that analysis.

Thailand had an impressive agricultural growth performance. Over the period 1961-1990 world agricultural production grew at an average annual rate of 2.3 percent whereas that of Thailand grew at a 4 percent rate. Decomposing the output to three major components, crops, fruits (tree crops) and livestock, Thailand excelled in all three. The growth in fruit production was faster than that of crops and this indicates an intensification in the use of capital. Still, crops is the major subsector of agriculture, accounting for about three quarters of total agricultural value added. Thailand's performance is even more impressive when viewed on a per capita basis as its output increased at an average annual rate of 1.6 percent compared to 0.6 percent for the world as a whole. Thailand could achieve such a performance by maintaining strong exports which varied in the last four decades, on average, between 13 to 17 percent of agricultural output whereas at the same time its import fluctuated between 1.9 to 5.4 percent. Cultivated land increased from 8.3 million hectares in 1950 to 23.6 in 1990. This new land was obtained by clearance of forests. The annual average growth rate of land amounted to 2.84 percent, implying that the output-land ratio increased at an annual average rate of about 1.2 percent. Agricultural labor increased over the period 1954 to 1990 from 9.0 millions to 20.1 millions, an average annual growth rate of 2.1 percent. Data for other inputs are available only for the period beginning in 1961, and therefore subsequent analysis covers only the period 1961-1990. During this period the average annual growth rates of inputs per hectare, in percent, are: agricultural labor -0.42, fertilizers 9.5, irrigation 2.2, tractors 14.8. These developments can not be explained by more favorable prices because the price ratio of agriculture to that of non-agriculture trended downward over the period, particularly from the mid 1970s. It is clear that the drastic expansion in cultivated land was accompanied by a considerable intensification in the use of capital as measured by the increase in the application per hectare of fertilizers, tractors and irrigation. The labor use per hectare declined but at a relatively slow rate.

The land expansion that took place in Thailand was largely an initiative of the private sector, (Siamwalla et al). As to the future directions of Thai agriculture, "Thai agriculture is now at a crossroads. The two factors that fueled its past growth-surplus land and buoyant foreign market-cannot sustain it in the future. ...These developments ... present a set of delicate problems for the government. First, the factor intensity of Thai agriculture will change...At the same time, domestic demand will dictate that the more capital intensive and technology-intensive horticultural sector must expand." (Ibid p. 116).

From these comments it is clear that first, past behavior was the outcome of farmers decisions and second, the orientation of what will happen in the future and the role of government in it is focused on issues related to the extensive-intensive margins. With this background, we now turn to the analysis.

Our discussion suggests that land expansion can be explained by capital accumulation, the cost of reclamation, the terms of trade of agriculture and by the technology. Also, land expansion is expected to be positively correlated with the land augmentation measured by the increase of other inputs. Table 3 presents correlation coefficients between land and other variables. Obviously, the correlation between land and the other agricultural inputs is very high, and this is also the case on a per hectare basis. The second panel of the table shows the high positive correlation between land, length of roads and the investment and the low negative values between land and cost of road construction. This cost is taken as a partial indicator of the cost of clearing land for agricultural production.

The relationships between size of the agricultural land and these variables are summarized by some regressions presented in Table 4. The investment variable is for the economy as whole and it represents changes in resource availability. The table presents four empirical equations, the first and the third were obtained by OLS whereas the second and the fourth were obtained by instrumental variables. The last two equations were corrected for serial correlations. These regressions indicate clearly the strong positive relationships between land and capital accumulation, the terms of trade of agriculture, roads and the negative or zero relationships with the cost of construction.

Can this model account for the main developments of Thai agriculture? The joint expansion of land and of capital-land ratio required considerable resources, or simply capital. The question is what induced this big expansion? The terms of trade of agriculture were deteriorating over time, and this should have discourage expansion. The answer is capital accumulation, improvemnt in the infrustructure and technical change in agriculture. However, the major technological event in this area was the green revolution and this began in Thailand only in the late 1960s whereas land had been expanding rapidly even before then. The empirical analysis suggests that the capital availability and the decline in the cost of reclamation were important factors in this expansion.

Summary and Conclusion

The demand for land is determined jointly with the demand for the other inputs. As land is not homogeneous, the demand for it differs by its quality. What differentiates land from other inputs is that, for all practical purposes, it does not have alternative uses outside agriculture. It is in this sense that the land supply by quality is taken to be perfectly inelastic.[9]

One of the interesting outcomes of the analysis is that on the whole the shocks that call for land expansion, such as higher profitability for agriculture, or capital accumulation also call for land augmentation. However the strength of the response of the two margins is not the same and it is well known that most of the growth in agricultural output is coming out of increase in technology and changes in inputs other then land induced by the technical change. The present paper derives the determinants of the changes of the two margins in response to important attributes of the economic environment.

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[9]Some attributes of land can be affected by investment. The extension of the model to cover this possibility is not pursued here because it will not add an important insight to the present discussion.

Without a loss in generality, we include only one input other than land, referred to as capital. This can be viewed as an aggregate input. There is a cost of using land which can be interpreted in a variety of interesting ways. It can be thought of as the cost of reclamation or bringing land under cultivation. Or, it can be the cost of maintaining land quality, or the tax (subsidy) on land.

Turning to some more specific results, the first model analyzes the case where agriculture is a price taker and the technology is constant. In this case, an increase in the cost of capital reduces both land and capital. On the other hand, an increase in the land-tax rate affects only the cultivated area but not the level of intensity. However, the demand for capital declines because of the reduction in the area. A reduction in the product price has the same effect as an increase in the prices of the two inputs.

The second model examines the effect of capital constraint. The economic problem is to allocate the existing capital to the various quality lands. An important difference from the results of the first model is in that now an increase in the tax rate affects also the level of intensity because when land goes out of production, more capital is available for use on the cultivated land. As such, the land tax affects resource allocation and output.

The common feature of the these two models is that the signed effects are the same for land and the level of intensity. To break this similarity we need to differentiate between the substitution and expansion effects. The substitution effect is evaluated for a fixed output. This is done in the third model. In this model, changes in cost of capital or the tax rate on land generates an opposite effect on cultivated area and capital demand. The environment that favors augmentation, leads to land contraction.

Three types of technical change are considered for the price taker agriculture. Hicks neutral technical change acts like an increase in price. Land augmenting technical change reduces the marginal land quality and thereby increases the cultivated land as well as the intensive margin. The only case where the two margins may go in different directions in response to the technical change is when it is capital augmenting and the demand for capital is inelastic. In this case, the augmentation reduces the ratio of physical capital to land but increases the cultivated land. This scenario lacks empirical validity.

The response of the marginal land quality to the change in the economic environment is increasing with the factor share of capital on the marginal land. The degree to which a change in the marginal land quality affects the extensive margin is determined by the availability of marginal land, referred to as the thickness of the margin.

The response of the intensive margin to a similar change in the environment depends on the demand elasticity of capital. When the demand is very elastic, most of the changes will take place in the intensive rather in the extensive margin. This is an interesting case which is consistent with much of the developments in agriculture. When new techniques of production are more capital-intensive than the old ones, and agriculture is subject to capital constraint, there is a region in which the new and the old techniques coexist. In this regions, the demand elasticity for capital can be considered to be perfectly elastic and therefore most of the response to the changing environment will take place in the form of changes in the intensive, rather than the extensive margin. The pace of the shift to the new techniques depends largely on the rate of change of the supply of capital. This shift represents implementation of the new technique and it is in this sense that most of the growth in output comes from land augmentation rather than expansion.

It is common to talk of technical change in agriculture as land saving. This is true in a very specific meaning, namely holding output constant. As such, it represents only the substitution effect of the technical change. To assess its total effect, the expansion effect is added and this effect is in the same direction for the two inputs. The strength of the expansion effect reflects the demand and it is possible to think of situations where due to the low price elasticity for agriculture that the expansion effect caused by technical change will be small and perhaps weaker than the substitution effect. However, there is no evidence that this has been important.

Another way to think of land saving is what we refer to here as land augmentation, namely an increase in the ratio of capital to land. However, this measure does not tell us about the contribution of land to output. This information is given by the production elasticity of land. The empirical evidence indicates that land is still an important contributor to agricultural output.

An empirical application to Thai data produces results which are consistent with the theory. The dramatic expansion of land in the period 1950-1990 in Thailand was positively related to the capital availability in Thailand and to the terms of trade of agriculture. These two variables are also related to an increase in the input intensity, other than labor. The expansion was negatively, though insignificant, related to the cost of highway construction but positively related to the length of roads which can be thought of as representing a reduction in the cost of reclamation.

Appendix

Note 1 Details for deriving Property 4.

Solving (21), using (22), we obtain $\frac{\partial z}{\partial K} = \frac{\partial r}{\partial K}\frac{zk(z)}{c}$, or written as an elasticity:

$$E(z,K) = E(z,r)E(r,K) = E(r,K)\frac{S(k(z))}{S(c;z)} < 0. \tag{A.1}$$

$$E(A,K) = E(A,z)E(z,r)E(r,K) > 0. \tag{A.2}$$

The response of the capital intensity to a change in K is:

$$E(k(q),K) = -\sigma E(r,K) > 0 \tag{A.3}$$

To compare the response of the two margins to a change in K we divide (A.3) by (A.2) and the result is the same as that obtained for the first model.

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Table 1 - - summary information

Variable	# countries	Rates of growth Deciles (percent) 1	5	9	P(x=0)
Output	130	0.37	1.92	3.87	61
Output/land	87	-0.13	1.8	3.6	13
Output/labor	87	-0.5	2.0	4.6	16
Land	132	-1.8	0.4	2.1	35
Labor	148	-3.3	0.56	2.1	40
Capital	56	-1.7	1.05	6.35	29
Fixed capital	56	-0.64	2.1	8.7	16
Fixed capital/output	56	-1.7	1.6	4.9	27

NOTES

1. Unless indicated otherwise, the data is for agriculture. The sources are the works with Butzer, Crego and Larson listed in the References.

2. The growth rates were calculated from a regression of the logs of the variables on time.

3. The deciles are computed from unweighted distribution of country data.

Table 2. Summary results

Exogenous variables	k(q)	z	A	K	Y	R	r	p
	Endogenous variables							
	Agriculture is a price taker							
r/p	-	+	-	-	-	-	..	..
c/p	0	+	-	-	-	-	..	..
	Capital constraint							
K	+	-	+	..	+	+	-	..
c/p	+	+	-	..	-	-	-	..
	Output quota							
Y	+	-	+	+	..	+	..	+
r	-	-	+	-	..	+	..	+
c	+	+	-	+	..	-	..	+

Notes:
.. Irrelevant

Table 3 Thailand: Correlation coefficients (1961-1990)

Total inputs

	Agricultural land	Irrigation	Fertilizer	Tractor	Investment
Agricultural land	1	0.95	0.92	0.89	0.89
Irrigation		1	0.95	0.98	0.9
Fertilizer			1	0.95	0.97
Tractor				1	0.89
Investment					1

Inputs per hectare

	Irrigation	Fertilizer	Tractor	Investment
Irrigation	1	0.88	0.96	0.79
Fertilizer		1	0.93	0.95
Tractor			1	0.86
Investment				1

Variables related to land regression

	Land	State highways length	Provincial roads length	State highways construction cost	State highways maintenance cost	Provincial roads total cost*
Agricultural land	1	0.98	0.94	-.084	0.83	-0.147
State highway length		1	0.96			
Provincial roads length			1			
State highways construction costs				1	-0.042	0.56
State highways maintenance costs					1	-0.22

Note: *series is from 1975 to 1990 only

Table 4 Thailand: agricultural land expansion - regression analysis (1961-1990)

Regressions	Constant	Capital	Price of agriculture	Cost of highways	Length of roads	AR(1)	R^2	D.W.	Obs.
1	5.198 (10.15)	0.107 (8.45)	0.275 (4.59)	-0.004 (0.34)	0.277 (9.30)		0.990	0.874	30
2	7.004 (7.18)	0.171 (5.57)	0.163 (2.12)	-0.038 (1.74)	0.159 (2.74)		0.991	1.115	29
3	6.531 (8.68)	0.189 (3.98)	0.213 (3.25)	-0.009 (0.66)	0.133 (1.63)	0.484 (3.28)	0.993	1.800	29
4	6.751 (7.22)	0.197 (3.65)	0.197 (2.62)	-0.011 (0.46)	0.118 (1.26)	0.497 (3.19)	0.992	1.770	28

Notes: Regressions 1 and 3 were estimated using ordinary least squares.
Regressions 2 and 4 were estimated using two stage least squares using as instruments: Price of agriculture, capital, PEAK, relative price of rice to fertilizer, and the inputs: agricultural labor lagged one year, tractors, fertilizer, and irrigation.

Source: Mundlak (1993).

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