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Optimizing the Spatial Structure of the Agricultural Production Function

Important characteristics of spatial agricultural production functions are derived by introducing a non-negative curvilinear spatial demand function for production input intensities. Given the usual neoclassical rationale assumptions of spatial demand for capital and labor inputs under competitive environment of farming in developing agricultural economies, the optimal production levels are determined by optimizing spatial demand for production inputs. Decreasing price-to-transport costs ratio (that is, decrease in the prices of capital goods or increase in freight rates) and increasing wage-to-travel costs ratio (that is, increase in labor wages or decrease in the travel rate) expand the limits of the (spatial) optimal boundary of the demand for agricultural capital goods and labor input respectively. These effects occur on account of the operation of (positive) spatial price gradient and (negative) wage-gradient in the market region. It may be noted that elasticities of demand for production factors are spatially variant and have significant effects on the alterations in the structure of agricultural production. However, the spatial optimal solution of production has a complicated relationship with them. The price elasticity has negative and wage elasticity has positive spatial gradients in the market region. Farmers located in the periphery of the market region are not much affected by the proportionate changes occurring in the prices of agricultural capital goods but are more sensitive to the proportional changes in labor wages.

Because of a decreasing trend in capital input demand and increase in labor input with distance from the market, capital-product diminishes with a decreasing rate and labor-product increases with an increasing rate in the spatial structure of agricultural production. As a result, capital-labor ratio falls toward zero, which raises profit rate per unit of capital investment especially in the outer part of the market region. The equilibria of optimal production with price elasticity as well as of capital intensity with labor employment (that is, capital-labor ratio as unity) determine spatial limits of the optimal production zone which is shifted outward subject to the provision of cheap transportation, stabilizing market prices and/or increasing wage rate at the market center. It will help in extending outwardly the optimal spatial limits of capital investment and will mobilize capital resources of farmers in the periphery for efficient and competitive capital-dominated farming.

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It is widely accepted that agricultural intensity decreases with distance from the market (Dunn 1954; Garrison and Marble 1957; Katzman 1974). In the classical theories of agricultural location, spatial structure of land use is conventionally analyzed by determining economic rent per unit of land. These studies emphasize the intensity of land use with scant regard to the availability and demand for inputs. For example, assuming the effects of other factors that affect agricultural intensity as constant and considering a single output case, Thunen (cf. Hall 1966; Amedeo and Golledge 1975) and Dunn (1954) found a linear but negative relationship between economic rent and distance from the market. This relationship is lately specified as curvilinear (Visser 1980, 1982). The changes in the relationship of agricultural intensity and market access are dependent on technological advancement in agriculture as well as rural transport. The effects of technology are helpful in reducing production and transport costs in the spatial systems (Visser 1980). There are numerous papers on the comparisons of land rent with transport costs in spatial agriculture production system. O'Kelly (1988) examines the effect of transport on crop production while relaxing the assumptions of homogenous transportation cost imposed by O'Sullivan and Ralston (1980) and Macmillan (1982) for conditions of equivalence of consumer surplus and location rent. He notes that improvement in rural roads decreases costs on transportation and tends to increase farm gate prices of crop-products while decreasing market town prices. However, in agricultural phenomena, spatiotemporal behavior of capital and labor intensity may be quite different. Capital tends to be substituted for labor over time under improving (or changing) technology. However, unusual results of simultaneous decrease of capital and labor input intensities with respect to distance to market are observed in Visser's (1982) recent analysis.

Perhaps a decrease in the agricultural production intensity in its spatial structure is observed not only because of decline in the effects of market forces and transport technology, but also due to changes in the physical response of yield reproduction to the intensification of production inputs and yield-gaps (World Bank 1982; Smit, Brklacich, and Phillips 1991; Berry, Conkling, and Ray 1993, p. 246). The reproduction of agricultural yield is directly related to the absorption of production potential, which is wholly dependent on physical properties and agro-ecological conditions of land. The nutrients of soil are diluted and the production potential of land is absorbed for reproduction and growth of crop yield. Therefore, Mitscherlich (1909) states that diminishing response to reproduction diminishes marginal return to inputs (cf. Heady and Dillon 1961). Such situations of agricultural production may be optimized by considering following two scenarios:

Scenario 1: There is a strong available force of physical factors to produce crop yield with the dominance of high production potential and adequate carrying capacity of land. In this case, market does not play a significant role in developing agricultural activities. Monopoly in the distribution of production inputs and insignificant spatial competition are observed in the market region. Consequently, spatial structure of agricultural intensity is likely to be highly homogenous throughout the region while the level of productivity may be low.

Scenario 2: Market forces and technological advancements prevail simultaneously with a strong base of production potential in the agricultural landscape of the market region. The agricultural activities are organized and controlled by the market center. They alter the prevailing production function by substituting and/or diffusing agricultural technology for optimizing labor dominated agricultural intensity with significant effects of input prices and transport costs on it. According to Brinkmann's hypothesis on local comparative advantage and increasing locational importance, which was also supported by Learman and Conkling (1975) for specialization of agricultural production, increasing importance of the market location and decreasing transportation costs should alter production intensity. Spatial competition is also a likely outcome in such less developed agricultural landscapes where farmers are willing to enhance technology by substituting farm labor. Rural labor migrates toward nonagricultural sectors. Agricultural products are generally less income elastic than the demand for nonagricultural products and off-farm marketing services (Ghatak and Ingersent 1984).

Scenario 1 refers to the economic landscape of the underdeveloped regions where the impact of the market forces is negligible and optimization of production function is wholly dependent on physical conditions of land, especially the agrometeorological factors, to assess the maximum crop yield (Witek and Gorski 1977; Gorski and Spoz-Pac 1989; Gorski et al. 1994) and soil conditions of the land which control crop yield and maximization of the use of land potential (Grosjean and Messerli 1988; Prasad et al. 1987). On the other hand, Scenario 2 refers to a situation in an agricultural landscape of developing regions with well-organized socioeconomic activities as well as market forces to optimize the production function. Let us now speculate new dimensions of agricultural production function under Scenario 2 in which the attributes related to both production potential and market forces have an impact on the optimization of agricultural production function. The farm practices in the market region are labor intensive and passing through the phases of progressive economy with a centrally located market in the region. It is growing in its primary stage, acting as a diffusion center for technological innovations in agricultural farming practices and emerging with a continuous force of rural-to-urban migration. The market center concentrates the rural labor force. There is, therefore, much less production surplus to be transported to the market center. The spatial structure of agricultural intensity is thus addressed here by considering the effective prices of output and factor prices as spatially variant phenomenon in production. Optimization of the production function thus follows the criterion of agricultural rent maximization. However, farmers of a market region in a developing economy do have significant income accruing to them from their farming practices. As a result, farmers' income and prices of their products do not have significant effects on the spatial structure of the production function in the market region. This paper, then, addresses to a spatial structure of agricultural production which is wholly dependent on the spatial demand of production factors that are price dependent. The farmers of such a system are more sensitive to factor prices for intensifying their farming practices. However, the farmer's income and production prices are largely inelastic and are homogeneous throughout.

There are numerous studies on the development of intensity equations for analyzing spatial structure of agricultural land use (Kellerman 1983). In a more specialized review, Kellerman (1989a, 1989b) finds the relaxation of some assumptions and applications of the basic rent model of agricultural location theory. However, most of the studies revolve around the domain consisting of two parameters of a location rent model: the market prices of production and the effect of transportation costs (Webber 1973; O'Sullivan and Ralston 1980; O'Kelly 1988, 1989). The production price and location of production are determined by a rent model (Webber 1973). A specific kind of production function (that is, based on a logarithmic form of diminishing marginal return of yield to intensity) is used to determine optimal level of production intensity (Visser 1982) and also to establish the yield(farm size relation in its spatial context (Visser 1999). The findings of the dynamic model developed by Day and Tinney (1969) provide an explanation of land use equilibrium that is influenced by the price of production. Decreasing market prices affect long-term spatial equilibrium in increasing the supply of farm products (O'Kelly 1988). The production price adjusts itself to balance the variability in supply and demand, which is in turn dependent on transport cost (O'Kelly 1989).

On the other hand, studies on spatial competition and location of activities are heavily devoted to price equilibrium, profit maximization, search for optimal location for firms, problems of consumer distribution, and boundaries in spatial competition and so on (Teitz 1968; Gabszewicz and Thisse 1986; Gillen and Guccione 1993; Krider and Weinberg 1997; Pitts and Boardman 1998). Spatial competition and development of agricultural activities have different dimensions keeping in view a paradigm of a fixed location of a farm rather than variable locations of a firm in the market region. Spatial gradients of farm activities, therefore, align to the market center, which controls the spatial structure of agriculture. Deficiencies of the relevant literature on spatial structure of inputs intensity, its costs and agriculture production pattern are far too evident. A need for the application of microeconomic models related to spatial structure of the production function and its effects on technological changes in land use intensity are realized (Visser 1982, pp. 175–76). Given these concerns, we find two major areas in which the problems of spatial structure of agriculture may be addressed albeit with a limited scope. First, the effective price of farm output (that is, assumed as production surplus) and input costs are considered as determinants of profit on farm gate which vary spatially and optimize spatial structure of agriculture (Visser 1982). In fact, sensitivity of prices to input demand is equally important, which could not be taken up as a major determinant of farmer's demand. Secondly, varieties of agricultural production functions are tested in different agro-ecological conditions of land, but only the Cobb-Douglas production function is adopted to analyze the spatial structure of agriculture. It is, however, not highly suited to assess the effects of the production potential of land on the increase of agricultural production intensity due primarily to its parametric limitations.

The main objective of this paper is to examine (a) the characteristics of prices for capital goods, labor wage rates, and transportation costs, (b) their effects on altering the spatial structure of production intensity, and (c) to show the effects of changes in factors' prices (that is, price elasticity) on spatial boundaries of production intensity, useful for preparing spatial investment strategy. The Löschean (1954) approach of spatial demand and a suitable form of agricultural production function for the developing agricultural economies have been profitably used.

THE MODEL

Assume that agricultural production is a function of intensity of technological and labor inputs, measured by assessing the capital demand and availability of labor, that are price and wage dependent respectively in their spatial perspective. Also assume a simple delivered pricing policy of spatial system for capital demand of farmer/buyers, D, which is altered by the net price paid by farmers at their farm gate, p, located at a certain distance from the market, s, as $p(s) = (P + \alpha s)$, where P is factor price at market center and α is freight rate subject to $\alpha > 0$.

Further, on an imagined *isotropic* surface of a market region where the farmers' income is unchanged and factor demand is inelastic, all the farmers of the market region grow crops, buy inputs from centrally located markets, and use them fully for agricultural production at the location of their farms. Spatial demand for agricultural goods is therefore non-negative as $D(s) > 0$ with its curvilinear diminishing trend (Griffith 1986). The agricultural labor intensity, L, is spatially altered by the total available supply of the labor force, which is influenced by rural-to-urban migration, that is, wage dependent. Net wage rate at the farm gate, w, is assumed to be a negative linear function of distance to market as $w(s) = (W - \beta s)$ subject to $(W - \beta s) > 0$ because labor migration to market center is only possible when the market wage, W, is higher than total travel costs, βs. Of course, marginal spatial wage (that is, the differential wage between the market and the rural area) equals travel (or migration) costs (Visser 1982) because of linear negative wage gradient as $dw(s)/ds = -\beta$. Therefore, travel costs, β, determine the migration costs and destabilize labor intensity and unemployment in rural areas (Nakagome 1986). A condition of cut-off wage value, w^*, which is less than net wage, would determine a distance of an endogenous boundary of migration (labor supply to market), s^* where $w^* = (W - \beta s^*)$ and $s^* = [(W - w^*)/\beta]$. Outside the spatial boundary s^*, a few workers may move toward the market center and may survive only on subsistence wages and are likely to be pushed to the market for tiny jobs. Consequently, $s^* \geq s$ because $w^* \leq w$. This condition is helpful in setting the outer endogenous spatial boundary of the supply of the labor force to market center.

Let the spatial demand function for the intensity of production factors as suggested by Griffith (1986) be denoted:

$$D\,(P, s) = A\,(P + \alpha s)^{-\eta}\,, \tag{1}$$

and

$$L\,(W, s) = a\,(W - \beta s)^{-q}\,, \tag{2}$$

where η and q are price and wage elasticities of the demand for capital D and labor factors L, respectively, and A and a are maximum levels of factors when their demand is inelastic ($\eta = 0$ and $q = 0$). However, the nature of demand function is concave. Demand for production factors decreases non-negatively subject to their prices/wages. It means that negative consumption of these factors does not occur in agricultural farming in the market region as assumed earlier.

In order to achieve the best solution of factor demand, there are many equilibrium conditions of spatial structure of agricultural production as reviewed by O'Kelly and Bryan (1996). For example, land use equilibrium is influenced by price of production (Day and Tinney 1969). Land rent on a particular location is either subject to equivalence of consumers' (that are producers in present case) surplus (O'Sullivan and Ralston 1980; MacMillan 1982) or to the factor intensity (Visser 1982), or then to the reduction of transport costs through improvement of network with its nonhomogenous conditions (O'Kelly 1988). The profit maximization subject to factor prices is another important criterion for optimizing input demand (Lösch 1954; Greenhut, Hwang, and Ohta 1975). We need to take the partial derivative of the spatial demand function in such a way so as to satisfy maximization of farmers' land rent to optimize their factor intensity subject to the availability of production potential and factor prices at the site of their agricultural operations. In agricultural practices, a specific dose of input is required according to land quality and its potential. The ideal spatial demand range of production factors, that is, the spatial optimal endogenous boundary of the demand area from the market center at which factor demand falls to the minimum for agricultural practices subject to factor prices/wages, must satisfy the conditions $\partial D/\partial P = 0$ and $\partial L/\partial W = 0$. It does not exist in the present case; however, if it is approximately zero, as $1 \text{x} 10^{-t}$ ($t > 0$) is considered to be close enough to zero, then the spatial optimal endogenous boundary of the capital demand area, $\bar{s}$, and its optimal level, $\bar{D}$, are the solutions achieved by simplifying the conditions for s and D as

$$\bar{s} = [(A\eta . 10^{t})^{1/(1+\eta)} - P]/\alpha\,,$$

subject to ignoring $-ve$ sign of the term $(A\eta . 10^{t})$ because $\bar{s}$ is not $-ve$ quantity.

If $t = 0$ and $(A\eta)^{1/(1+\eta)} = K_1$ in the above equation, then

$$\bar{s} = (K_1 - P)/\alpha \text{ and } \bar{D} = A\,(K_1)^{-\eta} \text{ s.t. } \eta > 0\,, \tag{3}$$

and, similarly,

$$\hat{s} = (W - K_2)/\beta \text{ and } \bar{L} = a\,(K_2)^{-q} \text{ s.t. } q > 0\,, \tag{4}$$

where $K_2 = (aq)^{1/(1+q)}$, $\hat{s}$ is the spatial optimal endogenous boundary of labor demand and $\bar{L}$ is its optimal level. K_1 and K_2 are complicated terms, heavily loaded by elasticity coefficients. Optimal input intensities that maximize land rent do not vary as a function of distance but they are a function of price elasticity.

To say more about the spatial optimal demand boundary conditions related to price/wage, transportation costs, and the elasticity of demand, we consider a condition as ($K_1 \geq P$) in case of capital demand and ($K_2 \leq W$) in labor demand case [equations (3) and (4)]. Pricing policies and wage conditions play significant roles characterizing the spatial demand structure of production factors in farming practices. For instance, spatial optimal boundary of capital demand, $\bar{s}$, is reduced toward the market center as market prices as well as transport costs increase. It is reduced at a constant rate of $1/\alpha$ with respect to market price and at its rectangular hyperbolic form as freight rate increases because $d\bar{s}/dP = -1/\alpha < 0$ and $d\bar{s}/d\alpha = -[(K_1 - P)/\alpha^2]$ (Figure 1). On the other hand, labor demand increases with increasing rate in these conditions of negative spatial wage gradients because

$$\partial L\ (W, s)/\ \partial s = \beta qa\ (W - \beta s)^{-(1+q)} > 0 \text{ and, } \partial^2 L\ \ (W, s)/\ \partial s^2 > 0\ , \tag{5}$$

where net labor wages at the farm gate ($W - \beta s$) determine the following spatial wage conditions.

(i) Unitary net wage, that is, $(W - \beta s) = 1$; it will neutralize the effect of wage elasticity of labor demand at a particular distance from market center s_1 which is equal to $[(W - 1)/\beta]$ where the level of labor demand equals a and the rate of increase of labor intensity becomes βqa as explained by equation (5).

(ii) Zero-wage condition, that is, $(W - \beta s) = 0$; it will determine the extreme outer spatial boundary of no migration of workers to market center, s_2. Beyond this boundary, there is a condition of total labor supply to farm activities only.

In addition, it is to be noted that the wage-elasticity factor K_2 is one of the determinants of $\hat{s}$. It has three conditions as (i) $K_2 > 1$, then $0 < \hat{s} < s_1$; (ii) if $1 > K_2 > w^*$, then $s_1 < \hat{s} < s^*$ and (iii) if $K_2 < w^*$, then $s^* < \hat{s} < s_2$. The spatial optimal boundary for labor demand, $\hat{s}$, varies, thus, conditionally within the large spatial range of zero to s_2 not only because of K_2 but it increases as market wages increase and diminishes as travel costs increase because $d\hat{s}/dW = 1/\beta > 0$ and $d\hat{s}/\ d\beta = -[(W - K_2)/\beta^2]$.

By examining the simplified linear forms of equations (3) and (4) as $\bar{s} = [(K_1/\alpha) - (P/\alpha)]$ and $\hat{s} = [(W/\beta) - (K_2/\beta)]$, where (P/α) is price-transport cost ratio and (W/β) is wage-travel cost ratio in the spatial demand structure of agricultural pro-

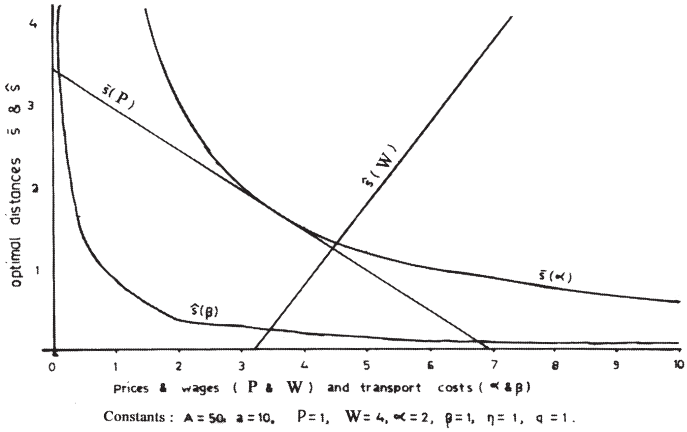


FIG. 1. Spatial Optimal Boundaries

duction, we conclude that the spatial optimal demand boundary for capital goods expands toward (K_1/α) as price-cost ratio falls to zero and this boundary for labor demand concentrates toward the market center when wage-cost ratio goes down. Notice that decreasing market prices/wages diminish price or wage-cost ratios. These attributes have no effect on optimal demand levels of capital goods nor on the labor factor of farm activities [see equations (3) and (4)]. The shifting of the spatial optimal demand boundary may be analyzed by fixing price-cost and wage-cost ratios constant and by concentrating our attention toward the impact of elastic demand on a spatial optimal demand structure.

ELASTIC DEMAND AND SPATIAL OPTIMAL BOUNDARY

Equations (3) and (4) provide a general solution which we desire. However, some specific cases will be helpful in understanding the effect of elastic demand on the spatial production structure, which is explained by the terms K_1 and K_2 in the general solution. If we fix the market price of agricultural capital goods (P), labor wage at market center (W), and transport costs (α and β) in the present case, we can then analyze the variable form of the general solution subject to the effectiveness of prices and wages. The price-cost ratio is fixed on 1:2 and wage-cost ratio on 4:1 because, in developing agricultural economies, freight rates are much higher due to a less efficient road network, traditional means of transportation, and weak transport sectors, while labor wage conditions are comparatively better on newly emerging market centers with high income elasticity of labor demand and more job opportunities prevailing on them (Ghatak and Ingersent 1984). We shall now examine the spatial optimal structure of input intensities considering their elastic demand conditions that are from unity onward (η and $\beta \geq 1$).

The structure of the term K_1 is formulated in such a way in the optimal solution [equations (3) and (4)] that, if η tends to increase from unity, it will increase the base of this term with a simultaneous decrease of its power function reciprocally. It means K_1 must diminish and, consequently, $\bar{s}$ must also tend toward zero as η tends to increase. Similarly, K_2 must decrease but $\hat{s}$ will increase as q tends to increase in the spatial structure of labor demand. Thus, the spatial optimal demand boundary concentrates toward the market center when capital demand is more elastic. Inversely, it expands outward in the market region as labor demand becomes more sensitive to wages. As a result, optimal levels of both capital and labor demand at its optimal boundaries diminish correspondingly (Table 1). The optimal capital-labor ratio shrinks gradually as the coefficient of price elasticity tends to rise. However, it increases fast as wage elasticity tends to increase infinitely because

TABLE 1
Critical Values of Optimal Factors Demand for Their Different Elasticity Coefficients

Elasticity	Capital demand			Labor demand			Capital-Labor Ratio		
η and q	K_1	$\bar{s}$	$\bar{D}(\bar{s})$	K_2	$\hat{s}$	$\bar{L}(\hat{s})$	$\bar{D}/\bar{L}$ (η, q)	$\bar{D}/\bar{L}$ (η)	$\bar{D}/\bar{L}(q)$
1	7.0711	3.0355	7.0711	3.1623	0.8377	3.1623	2.2361	2.2361	2.2361
2	4.6416	1.8208	2.3208	2.7144	1.2856	1.3572	1.7100	0.6299	7.9369
3	3.4996	1.2498	1.1666	2.3403	1.6596	0.7802	1.4953	0.2730	18.3133
4	2.8854	0.9427	0.7213	2.0913	1.9087	0.5228	1.3796	0.1508	33.1459
5	2.5099	0.7549	0.5020	1.9194	2.0806	0.3839	1.3076	0.0963	51.8968
6	2.2588	0.6294	0.3764	1.7948	2.2052	0.2992	1.2580	0.0676	73.9926
7	2.0797	0.5399	0.2971	1.7007	2.2993	0.2430	1.2226	0.0505	98.9380
8	1.9459	0.4729	0.2432	1.6272	2.3728	0.2034	1.1956	0.0396	126.2923
9	1.8421	0.4211	0.2047	1.5683	2.4317	0.1742	1.1751	0.0321	155.7826
10	1.7594	0.3797	0.1759	1.5199	2.4801	0.1520	1.1572	0.0267	186.9629

NOTES: See text for abbreviations of given column names. Notations: $A = 50$, $a = 10$, $P = 1$, $W = 4$, $\alpha = 2$, $\beta = 1$, η and $q = 1,2,3, \ldots, 10$.

$$\bar{D}/\bar{L}(\eta, q) = (A/a)[(K_2)^q/(K_1)^\eta] .$$

Further, solving basic demand function [equations (1) and (2)] for η and q respectively as

$$\eta\ (P, s) = \ln\ (A/D)\ [\ln\ (P + \alpha s)]^{-1} , \tag{6a}$$

and

$$q\ (W, s) = \ln\ (a/L)\ [\ln\ (W - \beta s)]^{-1} , \tag{6b}$$

it can be said that η and q are partially differentiable subject to the endogenous distance from the market center, s. Its first- and second-order solutions indicate a logarithmic relationship of elasticity with distance because

$$\partial\eta/\partial s = -\ [\alpha \ln\ (A/D)]\ [(P + \alpha s)\{\ln\ (P + \alpha s)\}^2]^{-1} , \tag{7a}$$

$$\partial^2\eta\ /\partial s^2 = [\alpha^2 \ln\ (A/D)\{2 + \ln(P + \alpha s)\}]\ [(P + \alpha s)^2\ \{\ln\ (P + \alpha s)\}^{-1}]^{-1} , \tag{7b}$$

and similarly

$$\partial q/\partial s = [\beta \ln\ (a/L)]\ [W - (\beta s)\{\ln\ (W - \beta s)\}^2]^{-1} , \tag{8a}$$

$$\partial^2 q/\partial s^2 = [\beta^2 \ln\ (a/L)\{2 + \ln(W - \beta s)\}]\ [(W - \beta s)^2\ \{\ln\ (W - \beta s)\}^{-1}]^{-1} . \tag{8b}$$

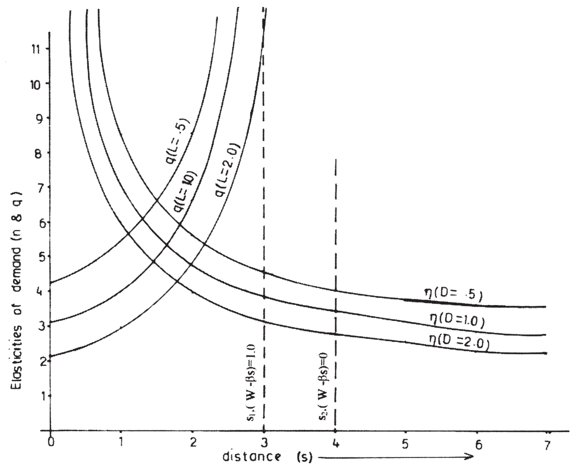
As increasing prices of capital goods and decreasing net wages at the farm gate located at a particular distance from the market center which act in the denominator of the fraction of first- and second-order solutions, the solution satisfies that η decreases with a diminishing rate and q increases with an increasing rate as distance to market increases. Wage elasticity is more sensitive to spatial structure of labor demand. It increases labor demand slowly in the close surroundings of the market center and very fast in the outer parts near s_2 where $(W - \beta s)$ tends close to zero (Figure 2). However, coefficients of elasticities (for both the cases η and q) at spatial optimal demand boundaries $\bar{s}$ and $\hat{s}$ must be recorded as

$$\eta(\bar{s}) = [\ln\ (A/D)](\ln K_1)^{-1} \text{ and } q(\hat{s}) = [\ln(a/L)](\ln K_2)^{-1} . \tag{9}$$

We may conclude that elasticities of demand are spatially variant, which gives differential availability over spaces of different types of production inputs. Peripheral farmers of the market region are not much affected by the proportionate changes of prices of agricultural capital goods but they are sensitive to the proportionate changes of labor wages. Percentage increases in labor wages will increase the rate of rural-to-urban migration and, consequently, will diminish disguised unemployment in agricultural activities in peripheral areas of a market region.

PRODUCTION INTENSITY AND DISTANCE TO MARKET

In order to derive a function for intensity of agricultural production, $Y(D,L)$, a specific production function must be utilized in which production potential parameters are reflected. Farm organization and technology (level of knowledge) are considered to be



Constants : A = 50, a = 10, P = 1, W = 4, α = 1, β = 1

FIG. 2. Trends of Elasticities at Various Levels of Their Factor Demand

important attributes for assessing actual productivity, which is always less than the level of maximum expected productivity because unpredictable changes and the lack of economic rationality create an uncertain environment for farming decisions. However, a farm can minimize productivity gaps and optimize the use of farm resources through employing risk aversion availability of inputs' knowledge (Wolpert 1964). Therefore, a production function that is based on the reciprocity law of diminishing marginal returns to intensity is applicable. It is chosen here to explain changes in factor ratios with market access (Singh 1980, 1994). The production function used here is

$$Y\,(D, L) = A_0\,[1 + (B_1/D) + (B_2/L)]^{-1}\,, \tag{10}$$

where Y, D, and L are non-negative variables, and A_0, B_1, and $B_2 > 0$ are constants. A_0 refers to level of maximum expected production and B_1 and B_2 are defined as maximum response of reproduction attainable by application of inputs D and L respectively for raising the existing production level. If D and/or L are intensified in the function, the level of existing production Y approaches A_0, so maximum response of reproduction per unit of input (B_1/D) or (B_2/L) tends toward zero. Therefore, marginal products to intensities, $\partial Y/\partial D$ and $\partial Y/\partial L$, decline non-negatively in present production function.

In order to derive the spatial characteristics of the production function, the defined factors spatial demand equations (1 and 2) are inserted into the function, considering the combined as well as the separate effects of the two factors, namely, the total product of the two factors combined, $Y(P, W, s)$, capital product (that is, production subject to the capital factor only, $Y_1\,(P, s)$), and labor product (as production subject to the labor factor, $Y_2\,(W, s)$). It shows that

$$Y(P, W, s) = A_0\,[1 + \{(B_1/A)(P + \alpha s)^{\eta}\} + \{(B_2/a)(W - \beta s)^{q}\}]^{-1}\,, \tag{11a}$$

$$Y_1(P, s) = A_0\,[1 + (B_1/A)(P + \alpha s)^{\eta}]^{-1}\,, \text{ and} \tag{11b}$$

$$Y_2(W, s) = A_0\,[1 + (B_2/a)(W - \beta s)^{q}]^{-1}\,. \tag{11c}$$

Careful inspection of the above equations reveals that capital product diminishes and labor product increases as distance to market increases. While their rates are determined by price/wage rates and transport costs, because of chain rule, we get

$$\partial Y_1(P,s)/\partial s = -\alpha\eta\,(B_1/A)\,[1 + (B_1/A)(P + \alpha s)^{\eta}]^{-2} < 0 \qquad (12a)$$

$$[(\partial Y/\partial D).\ (\partial D/\partial p).\ (\partial p/\partial s)]$$

$$\qquad\quad + \qquad\quad - \qquad\quad +$$

$$\partial^2 Y_1(P,s)/\partial s^2 > 0\,, \quad +dec \quad +dec \quad 0$$

and

$$\partial Y_2(W,s)/\partial s = \beta q\,(B_2/a)\,[1 + (B_2/a)(W - \beta s)^{q}]^{-2} > 0 \qquad (12b)$$

$$[(\partial Y/\partial L).\ (\partial L/\partial w).\ (\partial w/\partial s)]$$

$$\qquad\quad + \qquad\quad - \qquad\quad -$$

$$\partial^2 Y_2(W,s)/\partial s^2 > 0\,, \quad +dec \quad + \quad 0\,,$$

where the signs under arguments denote signs of corresponding first- and second-order derivatives in which $+dec$ indicates non-negative decrease.

The above derived equations also extend the argument that transport costs, α or β, are the main rate determinants that directly bear on the spatial structure of agricultural production. However, capital product follows asymptotic convergence (diminishing with decreasing rate) and labor product has the nature of increasing divergence in their spatial structure. Price elasticity alters the degree of asymptotic convergence in spatial production structure. If there are stable prices of capital inputs and, therefore, a regular supply of inputs from the market center (the case of very low price sensitivity, $\eta < 1$) such that the capital product [as equation (11b)] follows decreasing marginal return throughout, the ranges of its production volume and intensity are then higher with their lesser spatial variations in the market region (Figure 3). Level of production at the spatially optimal boundary of capital as well as of labor demand referred to here as optimal production, $\bar{Y}\,(\bar{s},\hat{s})$, varies with three parameters of the production function, namely, the level of maximum expected production A_0, the maximum response of reproduction B_1 or B_2, and the elasticity of factor demand η or q. Since A_0 and B_1 (or B_2) are considered constants, the optimal production is not the

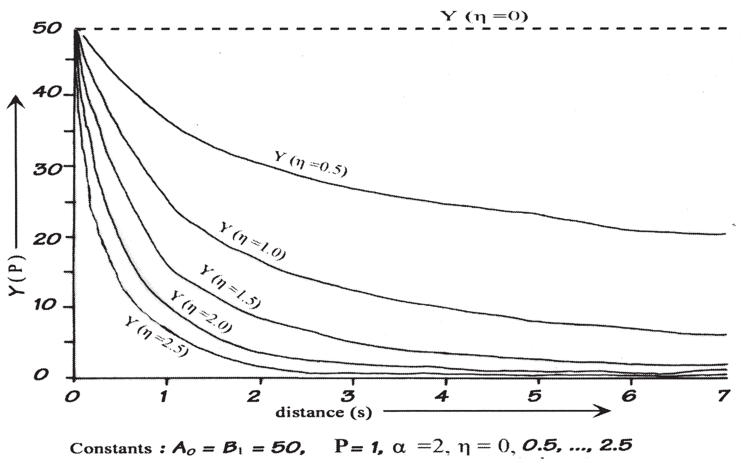


FIG. 3. Trends of Capital-Product at Various Elasticity Coefficients

function of parameters related to production potential or hidden capacities of land like soil fertility, climatic conditions, and so on; it is the function of elasticity of factors demand as

$$\bar{Y}(\bar{s},\hat{s}) = A_0[1 + \{(B_1/A)K_1{}^{\eta}\} + \{(B_2/a)K_2{}^{q}\}]^{-1} . \qquad (13)$$

If the capital as well as labor intensities are more sensitive to changes of their prices and wage rates, the level of optimal production in farm activities will be depressed because $[\partial\bar{Y}(\bar{s},\hat{s})/\partial\eta$ or $\partial q] < 0$ and $[\partial^2\bar{Y}(\bar{s},\hat{s})/\partial\eta^2$ or $\partial q^2] > 0$.

A numeric simulation indicated that since price elasticity of demand for capital goods declines and wage elasticity of labor input increases with distance from market, as argued earlier through equations (6a) and (6b), and the level of optimal production declines with the degree of elasticity as stated above, the level of optimal capital product, $\bar{Y}(\eta, s)$, then must increase with decreasing rate and, inversely, the level of optimal labor product, $\bar{Y}(q, s)$ must decrease with an increasing rate as distance to market increases (Table 2).

In such conditions of spatial structure of agriculture production where optimal intensities follow opposite trends of each other (because of spatial trends of price and wage elasticities), the spatial variations in optimal intensities may occur due to various reasons. Visser (1999) argues that quality of land varies due to locational differences. Due to falling rent with increasing distance, farm size increases as distance to market increases because farmers substitute the cheapening factor of production (that is, land at distant locations in market region) for others in their production processes (Berry, Conkling, and Ray 1993, pp. 256–57). Visser (1999) further argues more logically that farm size should increase with increasing distance in market region only if intensity varies spatially and if optimal scale economies are a function of farm size. Optimal production intensities vary spatially in the present case because price/wage elasticities are a function of distance to market. Price elasticity of the demand for capital goods is observed (it is greater and wage elasticity of labor demand is lesser) in farm locations closer to market, where farm sizes are usually smaller. It is because of opportunities for (i) adopting new technology and its demand for a large-scale operation even in farms of small size (that is, a case of higher coefficient of price elasticity) and (ii) a big market center where off-farm employment opportunities stabilize wage elasticity of farm labor closely surrounding the market center (that is, a case of lesser wage sensitivity). However, a farmer may tolerate sensitivity of price (or wage) fluctuations to a certain degree to optimize production in his farm located at a certain distance from the market.

Such arguments lead us toward a spatial spectrum of optimal intensities that are determined by equating a function of optimal production, $\bar{Y}(\bar{s},\hat{s})$, with its respective functions of price/wage elasticities, $\eta(s)$ and $q(s)$ and solving them for s to achieve specific spatial limits of the spectrum as sc (for optimal capital product) and sl (for optimal labor product). The farmers operating in the outer areas of such equilibria sc and sl, must have higher levels of optimal capital product with less price sensitivity of demand for capital goods and, otherwise, they also activate farming at a lower level of optimal labor product with a higher degree of its wage elasticity. This situation would help farmers by creating more demand for technological inputs and in-migrating rural labor to the market center. However, the spatial range of such equilibrium for sc is inversely influenced by market prices and transport costs. Expansion of this range is possible either by reducing prices of goods at the market center or by improving the transport network for the reduction of freight rates as also argued by O'Kelly (1989) for production of different crops prevailing in the market region. Contrary to it, spatial range for sl is expanded by increasing wage rates at market center, while travel costs have negative effects on it.

TABLE 2

Elasticity Values and Their Corresponding Intensities of Optimal Capital-Product and Labor-Product in Their Spatial Structure

Distance(s)	$\eta(s)$	$q(s)$	K_1	K_2	$(K_1)^\eta$	$(K_2)^q$	$\bar{Y}(\eta,s)$	$d\bar{Y}(\eta,s)/ds$	$\bar{Y}(q,s)$	$d\bar{Y}(q,s)/ds$
0	—	1.1073	—	3.1300	—	3.5377	—	—	5.3509	—
1	3.5608	1.1833	3.1149	3.1010	57.1552	3.8159	1.7195	1.7185	4.9802	0.3707
2	2.4307	1.2851	4.0519	3.0570	29.9941	4.2039	3.2264	1.5069	4.5414	0.4388
3	2.0124	1.4307	4.6218	2.9881	21.7704	4.7878	4.3917	1.1653	4.0100	0.5318
4	1.7804	1.6610	5.0252	2.8784	17.7147	5.7776	5.3434	0.9517	3.3458	0.6639
5	1.6315	2.0959	5.3261	2.6718	15.3157	7.8440	6.1291	0.7857	2.4863	0.8594
6	1.5252	3.3219	5.5630	2.2491	13.7008	14.7685	6.8023	0.6732	1.3361	1.1502
7	1.4446	231.41	5.7588	1.0339	12.5322	2240.4	7.3843	0.5820	0.0089	1.3272

NOTES: For $\bar{Y}(\eta,s)$ and $\bar{Y}(q,s)$, equation (13) is used where $\eta(s)$ and $q(s)$ are used as equations (6a) and (6b) respectively. Notations: A_0=100, B_1 and B_2=50, A=50, a=10, P=1, W=8, α=2, β=1, D=1, L=1, s=0, 1,2,…, 7.

CAPITAL-LABOR RATIO AND PROFIT FUNCTION

Profit-maximizing behavior and intensity of production of any product depend on substitutability of production factors and changes in the capital-labor ratio (D/L). It is a negative function of market access because increasing labor intensity and decreasing capital intensity from market center diminish capital-labor ratio with its decreasing rate as $\partial(D/L)/\partial s < 0$ and $\partial^2(D/L)/\partial s^2 > 0$, but it decreases non-negatively. Let us consider a specific simple case of less elastic demand for capital goods and labor supply subject to capital prices and labor wages respectively as $\eta = 1$ and $q = 1$ in which $D/L(s) = [A(W - \beta s) / a(P + \alpha s)]$, where transport costs (freight rate and movement cost, α and β) have negative effects. In such conditions, spatial limit at a particular distance from market center, $s^{\#}$, where $(D/L) = 1.00$ and $s^{\#} = [(AW - aP)/(A\beta + a\alpha)]$, s.t. ($AW > aP$), can be imposed to distinguish the market region into two areas: the prevalence of a capital-dominated farming area from zero to $s^{\#}$ distance, and a labor-dominated farming area from $s^{\#}$ to s_2 distance. In such peripheral areas of market region, the level of agriculture yield becomes lower and it tends to decrease with distance. Diseconomies of scale also occur as result of an increase in farm area in production processes (Visser 1999). An ideal range of capital-dominated farming, $s^{\#}$, is comparable with the real ranges of spatial spectrum working in optimal production intensities, sc and sl, for accelerating a spatial decision-making process. The difference between ideal and real ranges as ($s^{\#}-sc$) as well as ($s^{\#}-sl$) determine optimal production zones, which provide a continuous space for technological enhancement in these fringe areas of labor-dominated farming practices. Transformation of agricultural processes in such areas may take place to reduce the labor intensity through greater labor mobility due to moderate wage sensitivity of agriculture labor demand. Labor intensity is, thus, substituted by increasing capital intensity because of higher price-elasticity conditions and fast adoption of modern technology. The nature and characteristics of farming systems prevailing in such optimal spaces of market regions are questions for detailed investigation. However, it may be concluded that the movement and width of such zones are functions of market prices, wage rates, transportation costs, and the ratio of production function parameters, B/A_0, subject to its three conditions: $s^{\#}$ may be lesser than, equal to, or greater than sc or sl. Expansion of such spatial optimal production areas is possible either by providing cheaper transport (reduction of transport costs) or by stabilizing prices at market center because $\partial s^{\#}/\partial\alpha$ and $\partial sc/\partial\alpha < 0$ and also $\partial s^{\#}/\partial P$ and $\partial sc/\partial P < 0$.

With diminishing return to intensity in present production function, average productivity of labor, Y/L, must be greater than its marginal product, $\partial Y/\partial L$, with an increase in their differences (which indicates rent of labor) as labor increases in the farming system. Increasing labor rent increases their real wages (rent plus subsistence wage). In the pricing of fixed factor-ratio, the economic rent according to microeconomic theories is the payment to a factor over and above that required to keep the factor in its current employment. It is called "production surplus" by the classical economists (cf. Koutsoyiannis 1975). Thus, it adds to the profit of a farmer on his farm in the given scenario of labor-intensive farming practices of developing economies where rent is considered as a part of profit and profit rate is altered by labor intensity in the unlimited supply of labor conditions. If the profit of a farmer, π, is productivity dependent as $\pi = [Y(L) - wL]$, where w is net wage and L is labor employment in the farming system, the profit rate per unit of capital investment must be

$$\pi / \mathrm{D} = [(\mathrm{Y} - \mathrm{w}L) / \mathrm{D}], \text{ and}$$

$$\pi / D(s) = \left[\frac{(P+\alpha s)^{\eta}}{A}\right] \cdot \left[\frac{A_0}{1+(B_2 / a)(W-\beta s)^{q}} - a(W-\beta s)^{(1-q)}\right]. \tag{14}$$

As the capital-labor ratio tends toward zero in the spatial demand function, it will raise the profit rate per unit of capital investment in spatial structure of production because first- and second-order solutions of profit function satisfy that $\partial(\pi/D)/\partial s > 0$ and $\partial^2(\pi/D)/\partial s^2 > 0$. Profit rate increases significantly faster in outer parts of a market region. It is also interesting to note that profit function is also differentiable subject to price elasticity of capital demand as $\partial(\pi/D)/\partial\eta > 0$ and $\partial^2(\pi/D)/\partial\eta^2 > 0$. It means that increasing price elasticity in the spatial structure of agriculture production increases the speed of the profit rate very fast in outer parts subject to spatial wage condition as $(W - \beta s) = 0$ (Figure 4).

The relationship of profit to capital must help in understanding the outward movement of the optimal production zone of a market region. It can be generalized that there are fairly good opportunities for capital investment in labor-dominated farming between endogenous distances of $s^{\#}$ and sc in outer parts of the market region. Appropriate technological goods may intensify capital inputs by reducing freight rates, which will help to expand spatial limits of the optimal production zone or capital investment near the outer boundary of the zone near sc. The intensification of technological inputs especially in the peripheral areas of the market region would also strengthen the profit-capital relationship of the farmers, would make them more competitive in their farming practices, and would also intensify the effects of their limited capital resources by substituting agricultural technology for production intensity.

CONCLUSION

The presently employed model offers some insights into the characteristics of spatial demand for agricultural inputs in a market region. In general, demand for capital goods diminishes and demand for labor increases as a result of a positive spatial price gradient and a negative spatial labor wage gradient, which refer to less available capital goods and a more available labor force at the farm gate as the distance to market increases. The prevailing conditions diminish the capital-labor ratio in its spatial perspective. In particular, spatial limits of optimal demand for capital goods and labor input are differentiable with factors prices, labor wage rates, transport costs, and elasticities of demand for capital as well as labor inputs subject to their prices/wages. In such conditions, the spatial boundary of optimal demand is concentrated toward market center as market prices and/or transport costs increase, while an increase in market wages extends the spatial optimal boundary of labor demand outward. Since

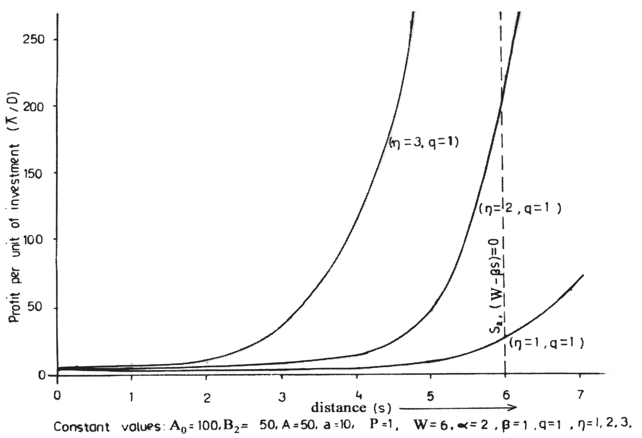


FIG. 4. Spatial Trends of Profit at Various Price-Elasticity Coefficients

optimal production intensity is the function of optimal factor demand, the optimal production level follows similar spatial tendencies with the effects of additional parameters related to production function. However, elasticity of factor demand, which is spatially variant, has a strong bearing on the spatial demand structure and, consequently, on production intensity. There are five important deductions from the present analysis.

(i) Capital production diminishes to follow asymptotic convergence (decrease with decreasing rate) and, inversely, labor product follows a trend of divergence (increase with increasing rate) with following the similar trends of the demands of their corresponding production factors in spatial structure of agricultural production. As a result, farming practices in locations close to the market center are capital-dominated and those in outer areas of market regions are labor-dominated.

(ii) The capital-labor ratio falls down rapidly as distance to market increases. The relative factor prices at the farm gate, w/p, also diminish in the spatial structure of agriculture. Technological progress will extend spatial margins to profitability by a capital-deepening factor ratio. As a result, relative prices at the farm gate will be increased either by increasing net labor wage rates or by decreasing input costs. Thus, technological intensification may improve the trend of capital-labor ratio.

(iii) Interestingly, optimal production intensity is a function of price/wage elasticity of production factors demand rather than transport costs. Elasticity varies spatially. Since price elasticity of capital goods declines and wage elasticity of labor demand increases as distance to market increases, the level of optimal capital production is expanded in its spatial structure either by decreasing factor prices or by increasing the wage rate at the market center.

(iv) The solution of optimal agricultural production is "zone-based" rather than "point-based." The optimal production zone is changeable subject to the relative market prices, relative transport rate, and ratio of production function parameters. Increase in these parameters, of factors' demand and production function, shifts optimal production zones outward in a market region through increasing farmers' profit per unit of capital in the zone.

(v) Generally speaking, these results suggest the optimization of spatial agricultural production structure, which is dependent on input demand and is governed by prices/wages, transport costs, and its elasticities. Some important parameters of the spatial structure of production function, namely, the maximum expected production limits and the degree of response of reproduction attainable at various input factors, are assumed to be constant, but may provide other solutions of spatial optimization, if they are considered variables in production structure of market region.

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