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Capital accumulation and the growth of aggregate agricultural production

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ABSTRACT

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This report empirically examines the role which capital accumulation plays in the growth of agricultural production potential. The report assumes that the degree to which available technology can be implemented in a nation's agricultural sector depends on accumulated investments that have been made in the sector. Results from estimating aggregate agricultural production functions show the primary importance of rural labor in accounting for agricultural GDP and crop production. Capital accumulation is the dominant explainer of livestock production. Estimation results support the conjecture that capital tends to save scarce land resources (substitute relationship) and use rural labor (complementarity relationship). Output supply elasticities derived from the estimated equations tend to be large. The large elasticities imply that price distortions have had large impacts on resource use and production.

INTRODUCTION

It has been estimated that in 2000, total food production in less developed countries (LDC's) will fall short of demand by 80 million t (Paulino, 1984). Excluding Latin America, LDC's will need to import more than 11% of their consumption demand. The problem has been especially severe for sub-Saharan Africa. The production growth rate as a percentage of the food consumption growth rate has been 67%, whereas the world mean has been 105%, and the LDC mean, 93%. For Latin America, although agricultural production growth rates have been high, the growth rates for

t, metric tonne = 1000 kg.

imports have been high as well, and net agricultural exports have dropped by nearly two-thirds since the early 1960's. This situation appears more striking when one realizes that LDC's as a whole were virtually self-sufficient in food production in the 1950's.

Mellor and Johnston (1984) have tried to explain the change in agricultural trade patterns. They emphasize the importance of high rates of population growth and the lack of LDC investment in their agricultural sectors. They note that many LDC's have pursued a dualistic growth strategy in which investment in agriculture has been ignored in favor of investment in industrialized sectors. Recent USDA studies (1988, 1989) have summarized the wide array of LDC sectoral and macroeconomic policies which have effectively taxed or discriminated against LDC agricultural sectors. Krissoff et al. (1989) calculate that if LDC's liberalize their agricultural markets in the context of industrialized countries liberalizing their markets, they stand to improve their agricultural trade position by \$25 billion/year. The LDC's could realize net welfare gains close to \$10 billion/year.

Krissoff and the others make their calculations on the basis of efficiency gains and exchange rate changes which are likely to result from worldwide agricultural trade liberalization in the medium term (3–5 years). Increased gross domestic products (GDP) of LDC's should also increase the pool of savings available for domestic investment. Although Krissoff and the others consider the effect of increased GDP on agricultural consumption, they do not cover the production gains which might result from additional funds available for agricultural investment, and from other longer-term resource adjustments. These omissions are reasonable because estimates of increased agricultural productivity due to increased investment in agricultural sectors do not exist for most countries. Furthermore, the theory which relates capital accumulation to agricultural growth has not been widely known or used among agricultural production economists.

The purpose of this report is to empirically examine the role which capital accumulation plays in the growth of agricultural production potential. The specific goals are as follows:

- Develop/adapt approach that targets technology and resource constraints in measuring the contribution of factors to agricultural growth potential.
- Analyze the importance of technological change and factor endowments to agricultural growth potential.
- Examine the nature of technology and factor substitution possibilities.

billion (US) = 10^9 .

- Estimate aggregate supply response to changes in agricultural production incentives. If LDC's were to effectively remove existing distortions which tax their agricultural sectors, what would be the likely effect on production over the medium to long term?

THEORY

Although agriculture has become increasingly research and capital-intensive, much of the increase in knowledge and application of new techniques has been unevenly distributed on a worldwide basis. Agricultural techniques differ across and even within individual countries. For empirical analysis, it has been conceptually difficult to account for changes in agricultural production as a function of change in usage of various agricultural inputs.

Much of the work applying production theory to LDC's originated with Schultz (1964). He objected to efforts which treated technological change as a residual from econometric estimation of production functions using time-series data. He argued that technology is always embodied in particular factors. New technology is adapted by employing a set of factors which differs from the set formerly employed.

Hayami and Ruttan (1971) extended Schultz's work by their use of a 'metaproduction' function, whose purpose was to measure the determinants important to agricultural development. They defined the metaproduction function as an envelope of all commonly conceived neoclassical production functions. They argued that agriculture adapts to changes in profitability by adjusting to a more efficient point on the metaproduction function. The readjustment acts through changes in the return to factors which are specific to agriculture. If the change in profitability is perceived to be sufficiently long lasting, then factor reallocations will take place. The reallocation of factors will affect the nation's ability to produce agricultural commodities. The metaproduction function is thus like an efficiency frontier. The position on which a country finds itself depends on the factor price ratios in that country.

The Hayami and Ruttan approach has been criticized by Mundlak (1980). He has argued that it is more than differing factor price ratios that can be used to explain differing inter-country input-output relationships. Mundlak's framework emphasizes that all countries have access to a set of techniques (that is, agricultural production functions) which constitute the technology of production. Technology is therefore a collection of techniques which are available for implementation. The motivation for changes in implemented techniques depends not only on changing factor price ratios but also, and more importantly, on the level of overall capital

accumulation in the economy. Because the adaption of a new technique does not exclude the possibility that existing capital is already committed, there can be simultaneous use of differing techniques in a region.

Although Mundlak's approach is similar to Solow's vintage capital model, a change in implemented techniques need not require the introduction of new physical capital. Investments in human capital can cause a reallocation of already committed capital into forms which constitute techniques different from those previously used. These investments can take the form of greater educational levels, extension services, farm size distribution, credit availability, input supplies, and adaptive research within a country. These factors relate to a nation's capacity to absorb advances in agricultural technology. Mundlak (1984, 1985) has maintained that the higher is the aggregate capital-labor ratio in a country's agricultural sector, the more likely it is that new advances in agricultural technology have been adapted in that country. The next two sections describe Mundlak's ideas in more depth. These ideas underlie the empirical model used in this paper.

Implemented technology

Supply analysis is typically based on the notion of a production function. The production function shows the maximum output attainable from any specified set of inputs. The meaning of the production function is clear when it describes a well defined process. In agriculture, this process could be the production of a crop under a set of well defined conditions. But in agriculture, there are many types of crops, as well as livestock, and many different sets of environmental conditions. This observation implies that there are a myriad of agricultural production functions. A crucial question is how to represent and measure technology when output is produced from more than one production technique.¹

The building block of production analysis is the technique, which is described by the production function. Technology (TN)² is a collection of all possible techniques, or production functions, for producing a product:

$$TN = \{F_j(x)\} \quad (1)$$

¹ The usual procedure is to fit a profit or cost function derived from microeconomic theory with aggregate times-series data. Constraints relating to convexity, homogeneity, and symmetry may be imposed in the estimation process.

² Technical change is typically discerned by the use a time trend variable. This approach relies on the notion of the representative producer. Chambers (1988) provides a useful discussion of the properties of the neoclassical production function, as well as a discussion of some problems and approaches to estimation.

where $F_j(x)$ is the production function associated with the j th technique, and x is the vector of factor inputs. The technology defines a convex input requirement set. It is the collection of all input requirement sets of all techniques for producing particular outputs.

The choice of techniques is a microeconomic decision made at the firm level. The producer maximizes profits, given input and output prices (w and p , respectively), and an endowment of fixed factors (k):

$$\max L = \sum_j p_j F_j(v_j, k_j) - \sum_j w v_j + \lambda \left(k - \sum_j k_j \right) \quad (2)$$

where $F_j \in T$. Optimality conditions for this problem can be derived to show that its solution depends on available technology (T_N), the fixed factor endowment k , and on output and variable input prices. These variables are referred to as state variables: $s\{k, p, w, T_N\}$. The optimality conditions can be arranged to produce:

$$0 = \sum_j \left(p_j \frac{\partial F}{\partial v_j} - w_j \right) v_j + \sum_j \left(p_j \frac{\partial F}{\partial k_j} - \lambda \right) k_j \quad (3)$$

The terms in parentheses are marginal productivity conditions which hold with equality when a technique is implemented. If either of these terms is negative (implying that the value of the marginal product of a factor is less than its marginal cost), then the optimal level of variable and fixed input usage for producing output j is zero; that is, the technique is not used. The solution to equation (2) defines an implemented technology (IT) set:

$$IT(k, p, w, T_N) = \{F_j(v_j, k_j) \mid F_j(v_j^*, k_j^*) \neq 0 \quad F_j \in T_N\} \quad (4)$$

The implemented technology set is a subset of the technology set T_N . It differs from T_N because of the constraints faced by the firm.

Role of capital accumulation

In this study, implementation of new agricultural techniques depends on capital available to the agricultural sector. Consider a simplified situation where there exist two techniques in a country's agriculture. Technique 1 is a traditional, labor-intensive technique, and technique 2 is a modern, capital-intensive technique. In this example, it is assumed that only labor and capital are binding for agricultural production – land is an underutilized resource. The production functions describing both techniques are assumed to be concave and twice differentiable. Constant returns to scale

are assumed. Production per rural worker can be expressed:

$$y_1 = l_1 f_1(k_1) \quad (5)$$

$$y_2 = l_2 f_2(k_2) \quad (6)$$

where y_i is per capita production for the i th technique, l_i is the proportion of fully employed rural labor in technique i , and f_i is average labor productivity for technique i . For all values of the rural wage-rental ratio (ω), technique 2 is more capital-intensive than technique 1: $k_1(\omega) < k_2(\omega)$. The aggregate agricultural production function is as follows:

$$f(k_{ag}) = l_1 f_1(k_1) + l_2 f_2(k_2) \quad (7)$$

where $k_{ag} = l_1 k_1 + l_2 k_2$. Average labor productivity in agriculture is a labor weighted average of labor productivities corresponding to each technique. Differentiation of the definition of k_{ag} produces:

$$\frac{\partial l_1}{\partial k_{ag}} = \frac{1}{k_1 - k_2} < 0 \quad (8)$$

As capital is accumulated in the agricultural sector, the proportion of labor used in the labor-intensive technique declines. Let q_1 represent the output share of technique 1 in agricultural production:

$$q_1 = \frac{l_1 f_1(k_1)}{l_1 f_1(k_1) + (1 - l_1) f_2(k_2)} \quad (9)$$

As $l_1 \rightarrow 0$, $q_1 \rightarrow 0$; as $l_1 \rightarrow 1$, $q_1 \rightarrow 1$:

$$\frac{\partial q_1}{\partial l_1} > 0$$

Use of the chain rule implies:

$$\frac{dq_1}{dk_{ag}} = \frac{\partial q_1}{\partial l_1} \frac{\partial l_1}{\partial k_{ag}} < 0 \quad (10)$$

The share of the traditional technique in agricultural production declines as capital accumulation in agriculture takes place – even with no change in relative factor prices.

The implications of this discussion can be seen in Fig. 1. The unit isoquants of the two techniques are drawn, along with the isocost line tangent to both (slope = ω). The slope of a ray from the origin through the point on the unit isoquant for technique i , tangent to the isocost line, represents the relative capital intensity of technique i . A ray from the origin whose slope k corresponds to the actual capital intensity (the ratio

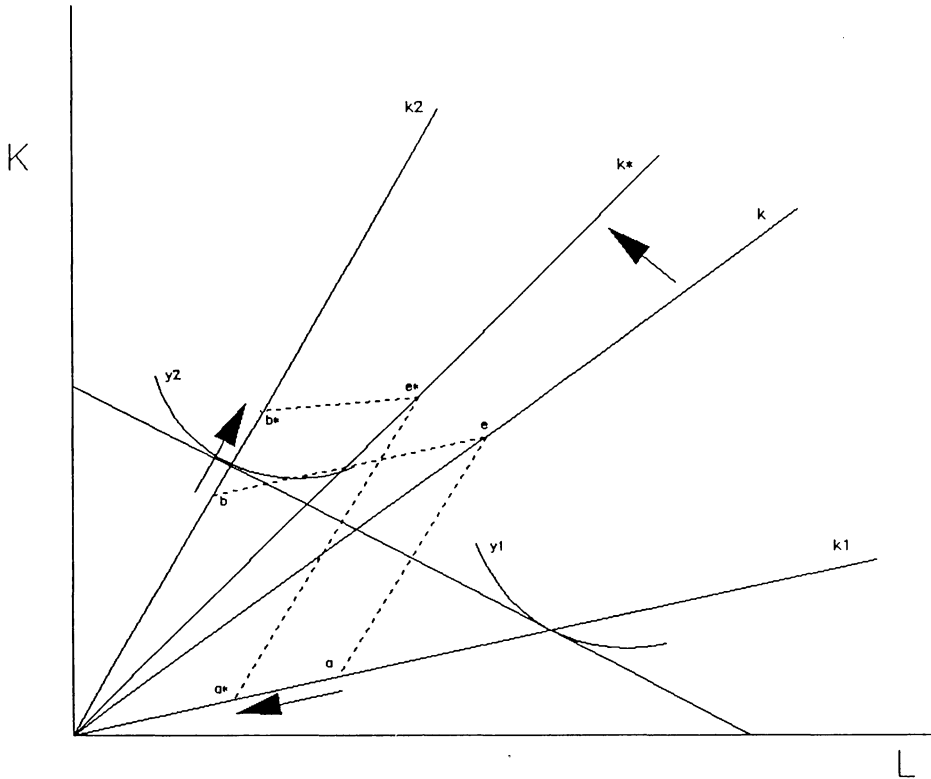


Fig. 1. Capital accumulation in agricultural sector.

of capital to labor endowments) in a country's agricultural sector identifies which techniques are employed. When $k_1 < k_{ag} < k_2$, both techniques are in use. Note the lines which originate at the endowment point e and whose slopes are equal to the slopes of the k_1 and k_2 rays. Where each of these lines intersects the corresponding k_1 or k_2 ray is an indication of the relative contribution of each technique to overall agricultural production. The more capital-intensive a nation's agriculture becomes (the closer is k to k_2), the greater is the share of technique 2 in agricultural production (as indicated by the arrows on the k_1 and k_2 rays as k is moved counterclockwise to k^*).

Capital accumulation results in the employment of capital intensive techniques. It is also true that the introduction of capital intensive techniques requires capital accumulation. In Fig. 1, technique 2 will not be used unless k is greater than the threshold level k_1 . The utilization of technique 2 increases as k increases. When k exceeds k_2 , only technique k_2 will be used. This discussion implies that the introduction of capital-intensive techniques is constrained by overall capital. Furthermore, the rate of

adoption of the capital-intensive technique depends on capital accumulation.

EMPIRICAL MODEL

Aggregate agricultural production is a function of state variables. The state variables represent technology and physical constraints to agricultural production.³ This study examines inter-country production relationships. The presumption of an approach which pools data from differing regions to estimate agricultural production relationships is that sufficient similarities in the technical basis for agricultural production exist so that pooling is valid and leads to an enhanced understanding of agricultural systems worldwide.

Agricultural production is represented as follows:

$$Y_i(t) = F(K_i(t), L_i(t), T_i(t)) \quad (11)$$

where Y is output, K is agricultural capital, L is rural labor, T is land, t indexes time, and i indexes a country or region. Land and rural labor represent basic resource endowments, or in other words, the constraint set of the state variables. Agricultural capital represents the technology component of the state variables.

The translog functional form was used in the estimation of equation (11) (Christensen et al., 1971). Implications of the translog are that partial elasticities of substitution between inputs are not constrained a priori, and that the productivities of individual factors in general depend on the level of the other factors. Substitutability and complementarity among factors can be discerned in the data and can differ from country to country, depending on factor endowments.

Production and resource data

Equation (11) was estimated using three different measures of agricultural production: agricultural gross domestic product, crop production, and livestock production. These data were derived from the Food and Agriculture Organization (FAO) index numbers (FAO *Production Yearbook*). In the case of agricultural production, there were deductions made for quanti-

³ Mundlak would argue for the inclusion of expected prices in the set of state variables. The presumption made in this paper is that expected prices are more appropriate for a country study where times series data are available to chart changes in implemented techniques.

ties used as seed and feed to avoid double-counting.⁴ These indices were used to adjust corresponding agricultural GDP, crop, and livestock data for 1980 to produce a time-series for the period 1967–88. These 1980 crop and livestock data are from FAO. The agricultural GDP data are basically from the *World Tables* of the World Bank (1989). In order to correct for disturbances due to possible climatic fluctuations or other random effects, the data were centered on base years of 1970, 1975, 1980, and 1985. In other words, the production data were averaged. (For example, production data for a particular country for 1967–72 are averaged, and the average thereafter is referred to as the 1970 observation for that country.)

Resource data correspond to agricultural labor and land. The labor variable is the agricultural labor force (in 1000) from FAO. While agricultural labor can be interpreted as a measure of direct labor input, it is probably best interpreted as an available input which is not necessarily fully or uniformly implemented across countries. The degree to which labor contributes to production depends on the level of the other production determinants of land and capital. The land variable is the total quantity of arable land (in 1000 hectares) from FAO. Arable land refers to land under temporary (as opposed to permanent) crops or lying fallow temporarily, and to pasture land. The labor and land data are centered on the base years as was the output data.

Capital data

There are no comprehensive measures of agricultural capital stock available for most developing countries.⁵ Other studies have used overall measures of capital availability, and have assumed monotonicity between overall capital and agricultural capital. Average labor productivity has been used as a proxy for a nation's capital abundance. This measure has been used by Mundlak and Hellinghausen (1982) and Haley and Abbott (1986). A second alternative is to calculate a capital series given gross domestic investment and assumed rates of depreciation. Bowen (1983) and Leamer (1984) have both applied this method in empirical examinations of compar-

⁴ Crop and livestock production levels are gross in the sense that there are no deductions made for seed or feed. Because seed and feed-to-livestock ratios will differ across both regions and time, consideration of three sets of dependent variables presents a broader picture of interrelationships between output and the state variables than restriction to a single set.

⁵ FAO in its *Economic Accounts For Agriculture* provides probably the best source for agricultural investment data. Even so, its country coverage is not wide enough nor its time-series long enough to suit the purposes of this study.

ative advantage theory. Another alternative followed in this study is based on a procedure recently adapted by Dadkhan and Zahedi (1986). Their method involves the simultaneous estimation of a production function and the rate of depreciation of the capital stock. A times series of the capital stock can be recovered from the estimated production function. Because the method has not been extensively used, we describe the methodology.

Dadkhan and Zahedi assume that gross domestic production can be represented by the following Leontief production function:

$$Q_t = \min(aK_t, bL_t) \quad (12)$$

where Q_t is output produced during period t , K_t is the capital stock at the beginning of period t , and L_t is labor utilized during period t . Assuming that capital is the limiting factor, equation (12) can be rewritten:

$$Q_t = aK_t + u_t \quad (13)$$

where u_t is an error term. Equation (13) can be combined with the capital stock identity:

$$K_t = (1 - \lambda)K_{t-1} + I_{t-1} \quad (14)$$

to produce:

$$Q_t = (1 - \lambda)Q_{t-1} + aI_{t-1} + v_t \quad (15)$$

where I_{t-1} is gross investment during period $t - 1$, λ is the depreciation rate, and $v_t = u_t - (1 - \lambda)u_{t-1}$. The authors suggest replacing I_{t-1} with I_t because during a one-year period, a substantial part of new investment will be in use as capital stock. Once equation (15) has been estimated, capital stocks can be recovered as:

$$\hat{K} = \frac{\hat{Q}_t - u_t}{\hat{a}} \quad (16)$$

The authors recognize the simple nature of the method. They note, however, that the method can be applied to a wide variety of countries, and that simulation analyses indicate the estimates provided by equation 16 are highly correlated with actual capital stocks in various countries where the stocks are known with some non-zero probability.

Real GDP and gross domestic investment data in terms of 1980 U.S. dollars. from the World Bank were used in estimating equation (15). The series ran from 1966 to 1986. The capital stock estimates were calculated for 1967 through 1986, but only the estimates for 1970, 1975, 1980 and 1985 were used in the study.⁶ In order to correct for the scale effects, the capital variable was divided by the agricultural labor force to provide a relative measure of the capital-labor ratio in agricultural sectors.

Country coverage

Equation (11) was fitted with data from 89 countries. The countries were classified according to stage of income development and geography. The income classification separated countries at varying stages of development. Low income developing region comprised countries where gross national product (GNP) per capita was between 100 and 400 1984 U.S. dollars (\$). The middle income developing region comprised countries whose per capita GNP was between \$400 and \$1700. The high income developing region was defined between \$1700 and \$5000 per capita. The developed region was defined over \$5000 per capita. The geographical grouping distinguished Africa, Latin America, Arab countries (including North Africa), Asia, and a residual area called 'temperate'. The temperate region comprised Europe, North America, and Oceania.

ESTIMATION

Several regression techniques were used in the estimation of equation (11) in the translog form. These techniques included ordinary least squares (OLS), a generalized least squares (GLS) procedure correcting for heteroscedasticity, and an instrumental variable (IV) approach. With one exception, we confine our discussion to the results from the IV technique. (All results are available from the author.) We explain below our rationale for implementing the IV approach.⁷

Measurement of capital and estimation

The theory presented earlier treated agricultural capital formation as a carrier of agricultural technology. The capital stock was retrieved from the production function regression parameter ' a ' (equation 15). This parame-

⁶ The appropriate estimation technique for equation (15) depends on the structure of the error term. Equation (15) was first estimated using ordinary least squares. Durbin's h -test was then run. In those cases where the null hypothesis of no autocorrelated disturbance term was rejected, a generalized least squares procedure adapted by Wallis was used. [See Johnston (1972, pp. 319–320) for a description and evaluation of the Wallis method.] In a few cases where the error term seemed to follow a first-degree moving average, an estimation technique based on the work of Zellner and Geisel (1968) was used. [Again, see Johnston (pp. 313–316) for a description and evaluation.]

⁷ We tested the alternative equation specifications underlying the IV and GLS techniques with a procedure from Hausman (1978). Results indicated that specification error associated with the GLS procedure was sufficiently serious to justify the alternative IV specification.

ter, because it was an estimate, was stochastic. The calculated capital series was also a proxy for unobserved agricultural capital. Dealing with an unobserved independent variable and stochastic independent variable are procedurally similar. We pursue this issue through a discussion of instrumental variables.

Instrumental variables. A method for dealing with unobserved variables (as described in Judge et al., 1982, pp. 537–539) involves representing the unknown variables (x^*) as linear combinations of observed independent explanatory variables (x). The model as described in Judge et al. is as follows:

$$y = x_1\alpha + x^*\beta + v \quad (17a)$$

$$x = x^* + u \quad (17b)$$

$$x^* = x_1\psi_1 + z_2\psi_2 + \dots + z_K\psi_K \quad (17c)$$

where x_1 is a column vector of ones, the ψ 's are additional unknowns, and the z 's are the additionally observed variables. In matrix notation, the β 's are estimated with the use of the instrumental variables (Z):

$$\tilde{\beta} = (x'Z(Z'Z)^{-1}Z'x)^{-1}x'Z(Z'Z)^{-1}Z'y \quad (17d)$$

Three additional variables were used in forming the Z matrix. The first was the quantity of fertilizer consumption (in metric tonnes) reported by FAO (*Fertilizer Yearbook*). This variable was divided by arable land to eliminate scale effects. The resulting fertilizer use per hectare represented the application of modern chemical (land-saving) technology. The second variable was the quantity-in-use of tractors. The series was also from FAO. The series was divided by agricultural labor to remove scale effects. The resulting variable tractors per unit rural labor represented mechanical (labor-saving) technology. The third variable was a land development cost index developed by Buringh et al. (1975). The index measures on a scale of 1 to 5 the level of development costs in preparing land for agricultural use. Low values represent low costs (minimum = \$200/hectare), and high values represent high costs (maximum = \$3000/hectare). All else constant (especially natural land endowments), low values of the development cost variable should correlate positively with past investments made in a country's agricultural land base.

Estimation results

Equation (11) was estimated using three differing dependent variables: agricultural GDP (AG), crop production (CROP), and livestock production

TABLE 1

F-test for equality of regression coefficients

Data grouping	Sum of squared errors		
	AG	CROP	LVSX
Full data set	105.91	85.80	206.69
Income groups			
Total	61.68	58.61	116.70
<i>F</i> -value	7.55	4.89	8.12
Geographical groups			
Total	56.88	47.05	77.02
<i>F</i> -value	6.59	6.30	12.88
Time groups			
Total	104.42	82.94	204.62
<i>F</i> -value	0.15	0.36	0.11

AG, agricultural production;
 CROP, crop production; and
 LVSX, livestock production.

(LVSX). As detailed earlier, the data were a pooled cross section of times series observations (that is, 1970, 1975, 1980, and 1985) for 89 countries. The observations were grouped three ways: according to the countries' income level, according to geographical location, and according to the year of the observation. The validity of pooling the data was tested by applying the general linear test (or Chow procedure) for determining the equality of regression coefficients across data groupings (Neter and Wasserman, 1974, p. 449).

Table 1 shows the total sum of squared errors and associated Chow statistics corresponding to the four ways the data were segregated for estimation. The sums form the basis of performing a general linear test (or Chow test) for determining the equality of regression coefficients across the data groupings. Rejection of the null hypothesis of the equality of coefficients calls into serious question the validity of pooling data. The *F*-values (or Chow statistics) indicate that coefficients are highly unlikely to be equal across the income or geographical groupings. The regression results based on the full data set are therefore likely to be misleading in their implications. In contrast, the *F*-values corresponding to the time grouping are low. The null hypothesis cannot be rejected with respect to the equality of coefficients over the sample period of 1970–85. Because the total sum of squared errors of the geographical grouping is far less than that of the income grouping, we conclude that geographical groupings are therefore

TABLE 2
Regression results

Region/Variable	Agricultural production			Crop production			Livestock production		
	Coefficient	SD	T-statistics	Coefficient	SD	T-statistics	Coefficient	SD	T-statistics
<i>Africa</i>									
Constant	13.394	3.530	3.794	15.779	2.741	5.756	8.064	4.323	1.865
<i>K</i>	−0.525	0.947	−0.554	−1.473	0.735	−2.003	−1.579	1.160	−1.362
<i>L</i>	−1.280	1.071	−1.195	−2.216	0.832	−2.665	0.853	1.311	0.650
<i>T</i>	0.224	0.619	0.362	0.643	0.480	1.339	−0.892	0.758	−1.177
<i>K</i> * * 2	0.174	0.152	1.146	0.306	0.118	2.591	0.737	0.186	3.961
<i>L</i> * * 2	1.298	0.355	3.653	0.627	0.276	2.271	0.218	0.435	0.500
<i>T</i> * * 2	1.075	0.310	3.471	0.225	0.240	0.936	0.528	0.379	1.393
<i>K</i> * <i>L</i>	0.323	0.186	1.739	0.269	0.144	1.862	0.358	0.228	1.571
<i>K</i> * <i>T</i>	−0.255	0.134	−1.901	−0.084	0.104	−0.806	−0.224	0.164	−1.366
<i>L</i> * <i>T</i>	−1.050	0.320	−3.287	−0.271	0.248	−1.092	−0.310	0.391	−0.792
	<i>R</i> ² = 0.773	<i>F</i> -Statistics: 42.501		<i>R</i> ² = 0.836	<i>F</i> -statistics: 91.06		<i>R</i> ² = 0.753	<i>F</i> -Statistics: 31.253	
<i>Arab countries</i>									
Constant	−1.037	3.550	−0.292	−7.024	10.973	−0.640	5.647	5.623	1.004
<i>K</i>	−1.836	1.271	−1.445	−0.888	3.927	−0.226	−4.392	2.013	−2.182
<i>L</i>	−0.962	1.429	−0.673	−0.435	4.416	−0.098	−3.298	2.263	−1.457
<i>T</i>	4.008	1.457	2.750	4.106	4.505	0.912	5.009	2.309	2.170
<i>K</i> * * 2	0.713	0.262	2.716	0.967	0.811	1.192	1.382	0.416	3.326
<i>L</i> * * 2	0.528	0.216	2.441	1.349	0.668	2.020	1.123	0.342	3.278
<i>T</i> * * 2	0.081	0.293	0.275	1.114	0.904	1.232	0.490	0.463	1.056
<i>K</i> * <i>L</i>	0.511	0.227	2.256	0.907	0.701	1.295	1.053	0.359	2.933
<i>K</i> * <i>T</i>	−0.441	0.160	−2.762	−0.988	0.494	−2.001	−0.857	0.253	−3.386
<i>L</i> * <i>T</i>	−0.421	0.212	−1.986	−1.347	0.656	−2.053	−0.856	0.336	−2.548
	<i>R</i> ² = 0.987	<i>F</i> -Statistics 71.963		<i>R</i> ² = 0.907	<i>F</i> -Statistics 46.476		<i>R</i> ² = 0.963	<i>F</i> -Statistics 39.369	

Asia									
Constant	6.586	3.255	2.023	5.720	1.841	3.107	13.110	4.784	2.741
K	−0.165	0.596	−0.277	0.009	0.337	0.028	0.495	0.885	0.560
L	2.213	1.623	1.364	1.061	0.918	1.155	−5.158	1.377	−3.747
T	−1.193	1.304	−0.914	0.144	0.738	0.195	4.492	0.968	4.639
K * * 2	0.188	0.060	3.120	0.014	0.034	0.417	0.007	0.073	0.102
L * * 2	−0.300	0.432	−0.694	−0.006	0.245	−0.024	1.228	0.275	4.467
T * * 2	−0.006	0.180	−0.034	0.050	0.102	0.491	0.449	0.117	3.828
K * L	−0.105	0.113	−0.928	−0.009	0.064	−0.141	0.231	0.164	1.407
K * T	0.138	0.095	1.451	0.032	0.054	0.597	−0.230	0.117	−1.962
L * T	0.145	0.289	0.501	−0.041	0.164	−0.248	−0.761	0.184	−4.144
	R ² = 0.933	F-Statistics: 188.770		R ² = 0.987	F-Statistics: 765.721		R ² = 0.970	F-Statistics: 172.550	
America									
Constant	1.877	2.521	0.745	11.116	1.610	6.904	−0.156	2.109	−0.074
K	1.331	0.729	1.826	0.181	0.465	0.389	1.075	0.547	1.966
L	2.791	0.820	3.401	0.756	0.524	1.442	2.261	0.731	3.091
T	−0.760	0.696	−1.091	−0.875	0.445	−1.969	−0.068	0.627	−0.109
K * * 2	−0.117	0.106	−1.102	0.256	0.068	−3.775	0.081	0.087	0.931
L * * 2	−0.401	0.377	−1.063	0.147	0.241	0.612	−0.228	0.359	−0.635
T * * 2	0.041	0.239	0.173	0.282	0.153	1.846	0.129	0.233	0.554
K * L	−0.135	0.171	−0.793	0.015	0.109	0.134	−0.103	0.151	−0.682
K * T	0.031	0.130	0.240	0.082	0.083	0.984	−0.027	0.117	−0.234
L * T	0.114	0.303	0.376	−0.175	0.194	−0.903	−0.016	0.289	−0.056
	R ² = 0.932	F-Statistics: 120.125		R ² = 0.971	F-Statistics: 303.404		R ² = 0.927	F-Statistics: 100.442	
Temperate region									
Constant	4.556	1.621	2.811	4.240	2.121	1.999	−9.406	2.907	−3.235
K	0.708	0.459	1.543	−0.401	0.601	−0.667	2.541	0.823	3.087
L	1.324	0.660	2.005	1.912	0.864	2.213	4.301	1.185	3.631
T	0.128	0.416	0.306	0.187	0.545	0.344	−0.293	0.747	−0.393
K * * 2	−0.040	0.081	−0.498	0.053	0.106	0.497	−0.118	0.146	−0.808
L * * 2	−0.125	0.126	−0.987	−0.390	0.165	−2.360	−0.625	0.227	−2.760
T * * 2	−0.090	0.051	−1.768	−0.183	0.067	−2.730	−0.005	0.092	−0.057
K * L	−0.087	0.075	−1.163	−0.064	0.098	−0.659	−0.127	0.134	−0.946
K * T	0.065	0.057	1.129	0.097	0.075	1.290	−0.046	0.103	−0.450
L * T	0.073	0.074	0.998	0.193	0.096	2.008	0.129	0.132	0.980
	R ² = 0.957	F-Statistics: 247.364		R ² = 0.965	F-Statistics: 270.068		R ² = 0.893	F-Statistics: 64.498	

TABLE 3

Estimated production elasticities

Region/Variable	Agricultural production		Crop production		Livestock production	
	Elasticity	SD	Elasticity	SD	Elasticity	SD
<i>Africa</i>						
Capital	0.1958	0.0878	0.3009	0.0682	0.4330	0.1075
Labor	0.8693	0.1161	0.7169	0.0901	0.6722	0.1421
Land	0.1451	0.1007	0.2131	0.0782	0.4196	0.1234
<i>Arab countries</i>						
Capital	0.5943	0.0726	0.7703	0.2245	0.7440	0.1150
Labor	1.0729	0.0886	1.2638	0.2737	1.2401	0.1403
Land	0.2019	0.0868	0.2792	0.2684	0.0426	0.1375
<i>Asia</i>						
Capital	0.4064	0.0726	0.2133	0.0410	0.7475	0.0795
Labor	0.4723	0.1621	0.6713	0.0917	0.2191	0.1680
Land	0.3398	0.1258	0.2493	0.0712	0.7921	0.1216
<i>Latin America</i>						
Capital	0.3231	0.0805	0.0733	0.0514	0.4661	0.0657
Labor	0.6215	0.0971	0.4723	0.0620	0.3537	0.1063
Land	0.3739	0.0737	0.3185	0.0471	0.6838	0.0804
<i>Temperate region</i>						
Capital	0.4530	0.0518	0.2830	0.0677	0.7070	0.0929
Labor	0.6335	0.0714	0.6798	0.0935	0.7552	0.1282
Land	0.2404	0.0555	0.4906	0.0727	0.1850	0.0996

considered preferable when examining production relationships in the context of inter-country analysis.

Table 2 shows the regression results for the geographical groupings. All regressions except the Asian livestock are IV regressions. The Asian livestock regression is OLS.⁸ Except for the African regressions, the *r*-squared values are close to or above 0.90. The African *r*-squared values are above 0.75. For each regression, *F*-statistics indicate that all coefficients are jointly different from zero.

Table 3 summarizes the regression results in terms of production elasticities. The elasticities were calculated by taking the derivatives of estimated equation (11) with respect to each of the three explanatory variables. (In the translog functional form, the levels of the explanatory variables help determine the value of the derivative. In the table results, mean values of

⁸ The Hausman statistic indicated that specification error associated with the OLS procedure was low. The IV results were also counterintuitive – in particular, the marginal productivity of the labor input was negative, contrary to expectations.

these variables were used to calculate the elasticities.) All the derivatives have the expected positive sign. Because the standard deviations corresponding to most of the elasticities are small relative to the elasticities, we conclude that most of the derivatives are statistically significant.

Interpretation. One way to judge the relative importance of variables is to standardize the effects of changes in variables by adjusting the elasticity by the ratio of the standard deviation of the dependent variable to the standard deviation of the explanatory variable. The result is often called a beta coefficient or standardized regression coefficient (Pindyck and Rubinfeld, 1981). A particular value of a beta coefficient means that a one standard deviation change in an explanatory variable leads to a standard deviation change equal to the value of the coefficient in the dependent variable, all else constant. The rescaling associated with the normalization

TABLE 4
Estimated beta coefficients

Region/variable	Agricultural production	Crop production	Livestock production
<i>Africa</i>			
Capital	0.1305	0.2192	0.2454
Labor	0.7721	0.6960	0.5078
Land	0.1478	0.2371	0.3633
<i>Arab countries</i>			
Capital	0.5091	0.5705	0.6797
Labor	1.2450	1.2679	1.5347
Land	0.1958	0.2341	0.0440
<i>Asia</i>			
Capital	0.4165	0.1699	0.8142
Labor	0.6372	0.7040	0.2790
Land	0.6132	0.3497	1.3494
<i>Latin America</i>			
Capital	0.2689	0.0621	0.3494
Labor	0.6167	0.4770	0.3055
Land	0.4496	0.3897	0.7159
<i>Temperate region</i>			
Capital	0.3841	0.1667	0.5280
Labor	0.6123	0.4565	0.6428
Land	0.3499	0.4960	0.2371
<i>Production-weighted average</i> ^a			
Capital	0.3672	0.1796	0.5547
Labor	0.6660	0.6193	0.5490
Land	0.4338	0.3936	0.5122

^a Weights based on averaged 1978–83 production levels.

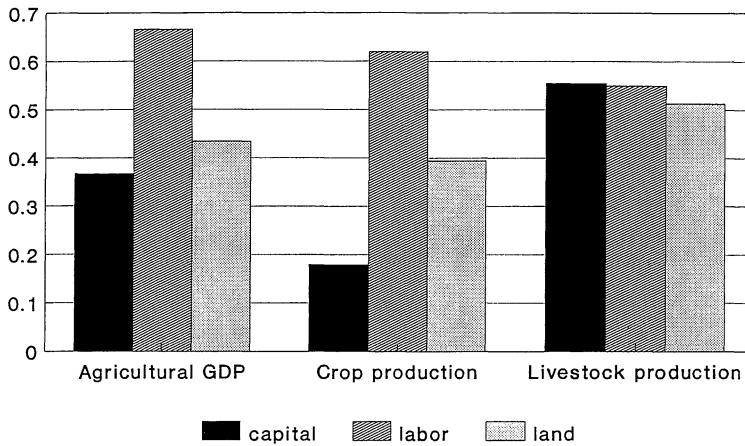


Fig. 2. Average beta coefficients.

makes it possible to compare the beta coefficients directly and judge the importance of one variable compared to another.

Table 4 shows the calculated beta coefficients for each geographical region. Using 1980 production levels as weights, the average beta values are shown in the bottom three rows. The coefficient values are depicted in bar chart form in Figs. 2–7. The coefficients reveal the importance of agricultural labor in producing agricultural GDP, crops, and livestock in all regions. Land varies in importance: being nonexistent in the Arab countries, but contributing much (especially) in the temperate region's crop production. Land contributes to Asia's and Latin America's livestock production, but is least important for the temperate region's livestock production. Somewhat

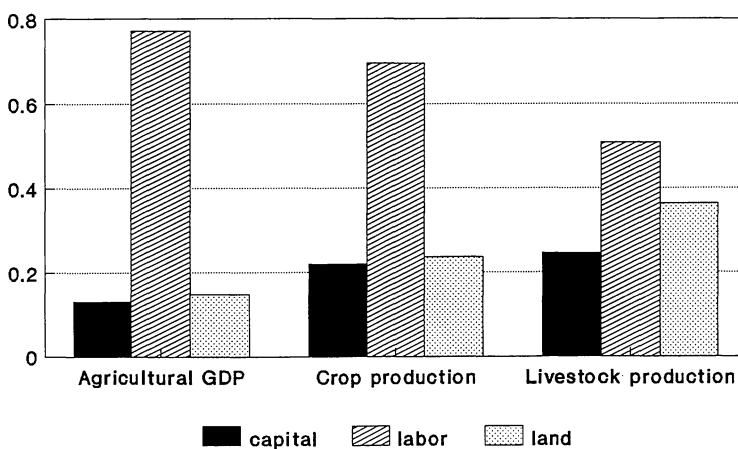


Fig. 3. African beta coefficients.

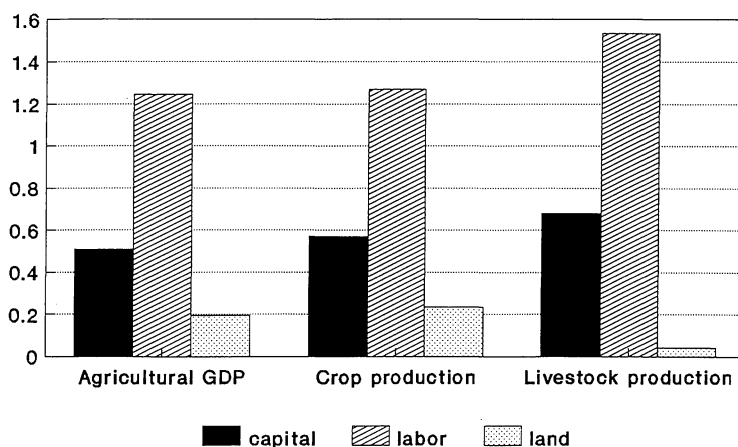


Fig. 4. Arab beta coefficients.

surprisingly, the presence of capital is the least important explainer of agricultural GDP and crop production, except in the Arab countries. In the Arab countries, capital likely compensates for a weak land base. Capital's greatest contribution is in livestock production. Its production-weighted beta value exceeds the labor and land beta values, even though all the beta's are close in value. There is also a great deal of variance in capital's contribution to livestock production. It is relatively small in Africa, but large in the temperate region.

Table 5 shows the ratio of the beta coefficients of the geographical regions to the production-weighted average beta values. A value less than one indicates a beta coefficient less than the world average, and a value

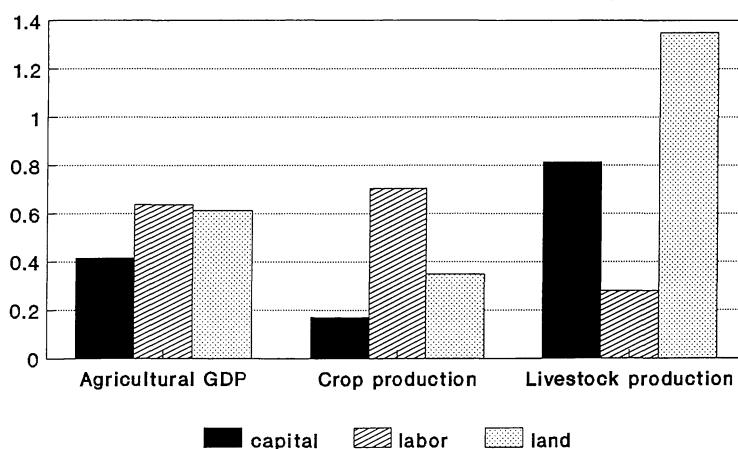


Fig. 5. Asian beta coefficients.

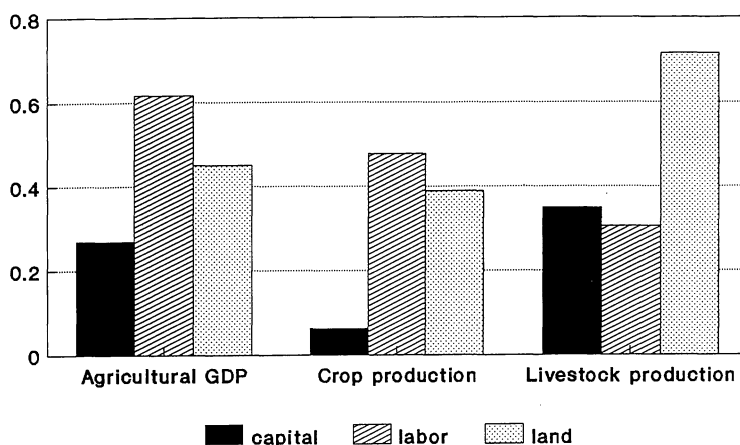


Fig. 6. Latin American beta coefficients.

greater than one indicates a value greater than the world average. Excepting the Arab grouping, Figs. 8–10 depict the ratios in bar chart form for agricultural GDP, crop production, and livestock production, respectively. The ratios help reveal the importance of capital, labor, and land for each of the geographical regions relative to the other regions.

The agricultural GDP ratios would be expected to fall between the crop and livestock ratios. This holds true for nine of the 15 cases. With the exception of African capital and land ratios, the other four ratios are close to falling within the range. In the African case, the low value of the agricultural GDP–capital ratio places some doubt on the high crop–capital ratio. The low agricultural GDP–land ratio, although it lies outside the

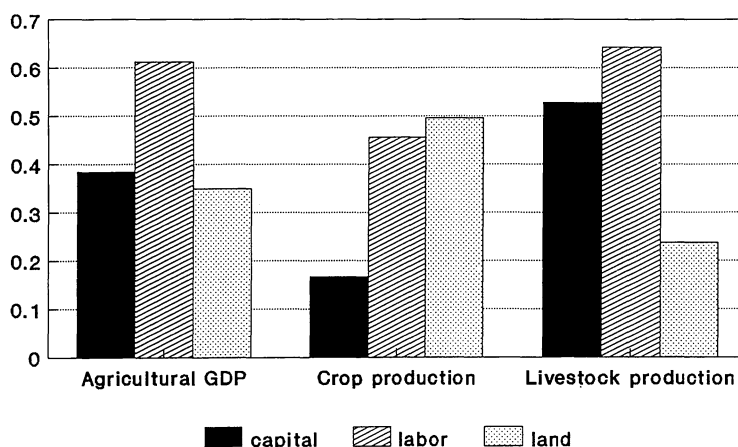
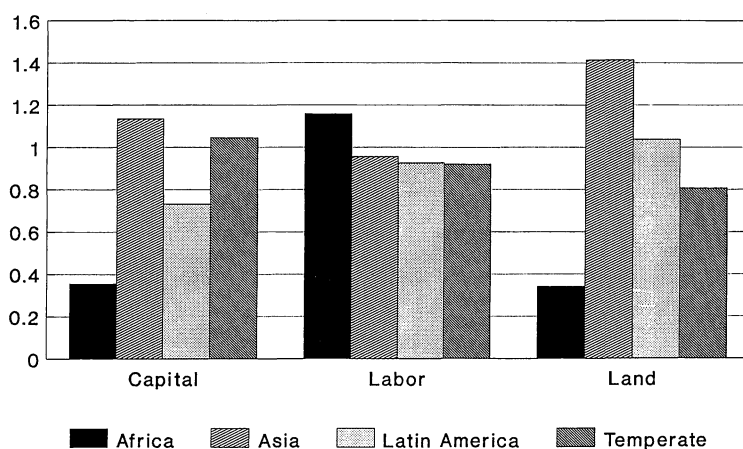


Fig. 7. Temperate region beta coefficients.

TABLE 5

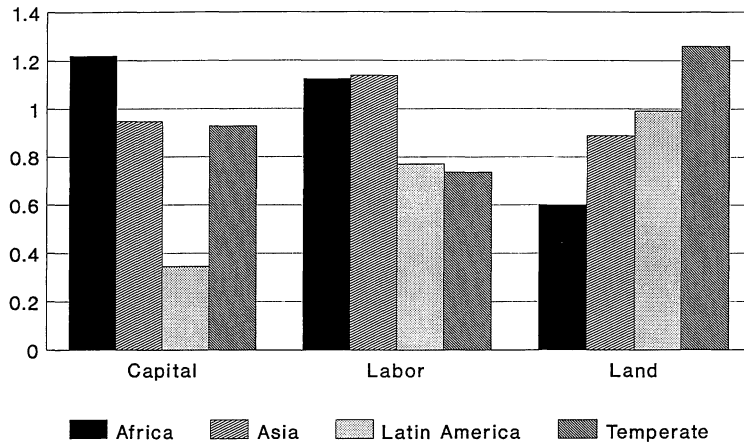
Ratio of beta coefficients to average coefficients

Geographical group and variable	Agricultural production	Crop production	Livestock production
<i>Africa</i>			
<i>K</i>	0.355	1.220	0.442
<i>L</i>	1.159	1.124	0.925
<i>T</i>	0.341	0.602	0.709
<i>Arab countries</i>			
<i>K</i>	1.386	3.176	1.225
<i>L</i>	1.869	2.047	2.796
<i>T</i>	0.451	0.595	0.086
<i>Asia</i>			
<i>K</i>	1.134	0.946	1.468
<i>L</i>	0.957	1.137	0.508
<i>T</i>	1.414	0.888	2.635
<i>Latin America</i>			
<i>K</i>	0.732	0.346	0.630
<i>L</i>	0.926	0.770	0.556
<i>T</i>	1.037	0.990	1.398
<i>Temperate region</i>			
<i>K</i>	1.046	0.928	0.952
<i>L</i>	0.919	0.737	1.171
<i>T</i>	0.807	1.260	0.463



Ratio of regional betas to average

Fig. 8. Distribution of production coefficients.

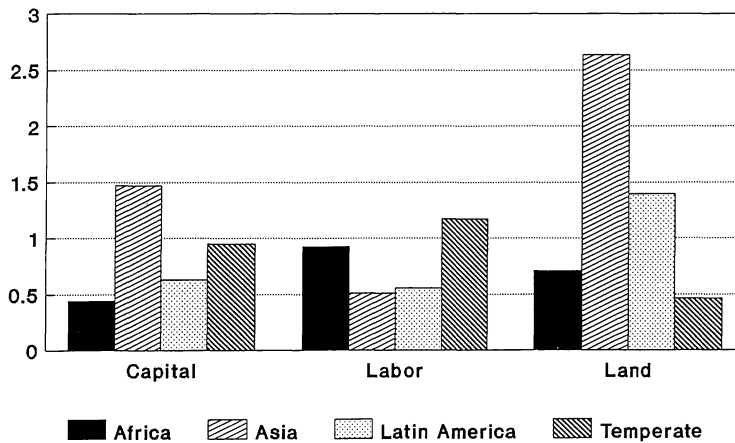


Ratio of regional betas to average

Fig. 9. Distribution of crop coefficients.

range, reinforces the implications of the other African land ratios – that is, that the African land resource is less important in influencing changes in crop and livestock production than other geographical regions, excepting the Arab region.

The capital ratios shows capital's importance to production in the Arab countries in particular, and also in Asia and in the temperate region as well. Labor is most important in the Arab countries and in Africa. The land resource is particularly important for crop production in the temperate



Ratio of regional betas to average

Fig. 10. Distribution of livestock coefficients.

region and in Latin America. Land is important for livestock production in Asia and in Latin America.

Elasticity of substitution

The growth of the agricultural state variables (capital, labor, and land) has been variable across regions and time. The growth of labor and land in particular has been mostly sluggish, while capital growth has been higher but still variable. It would be useful to discern the degree to which capital either substitutes for or complements these primary factors. One way to address this issue is to examine the elasticities of substitution implied by the aggregate production functions. The elasticity of substitution between two inputs measures the elasticity of their ratio with respect to their corresponding price ratio when either cost minimization or profit maximization is assumed, and when all else, including output, is held constant. The elasticity between two inputs i and j is defined in terms of a production function as:

$$\sigma_{ij} = \frac{x_1 f_1 + x_2 f_2 + \dots + x_n f_n}{x_i x_j} \frac{F_{ij}}{F} \quad (18)$$

where f_i is the derivative with respect to input i , F is the Hessian matrix, and F_{ij} is the cofactor of f_{ij} in F .

The elasticities of substitution calculated from the aggregate production functions in this study could be termed quasi-elasticities because they represent substitutability relationships among state variables rather than actual factor inputs. The estimated parameters (that is, regression coefficients) were used to derive the elasticities as specified in equation (18). These parameters are stochastic; that is, they each have an estimated mean value and standard deviation. This information is used to generate multiple estimates of each elasticity corresponding to the geographical grouping. The average of each elasticity and its estimated standard deviation are reported in Table 6.

Table 6 shows that the estimated elasticities are variable across both outputs and regions. For the most part, the standard deviations are large relative to the size of the elasticities. The statistical confidence that one may infer regarding the magnitude of the elasticities is therefore low in most cases. Nonetheless, the estimates consistently show that capital is complementary to labor, and it is a substitute for land. Labor and land tend to complement each other as well.

The elasticities seem to support the conjecture that the addition of agricultural capital and/or the adaption of new agricultural techniques

TABLE 6
Elasticities of substitution

Region/Input	Agricultural Production		Crop Production		Livestock Production	
	Elasticity	SD	Elasticity	SD	Elasticity	SD
<i>Africa</i>						
<i>K and L</i>	-1.44	1.97	-1.01	0.59	-1.04	0.97
<i>K and T</i>	0.07	4.02	0.99	0.27	0.99	0.36
<i>L and T</i>	-4.31	14.29	-0.98	0.38	-0.99	0.19
<i>Arab countries</i>						
<i>K and L</i>	-1.18	2.48	-0.87	0.36	-0.95	0.22
<i>K and T</i>	1.32	3.31	1.10	1.43	1.04	0.59
<i>L and T</i>	-0.15	7.71	-0.93	0.32	-0.87	0.30
<i>Asia</i>						
<i>K and L</i>	-2.38	15.30	-0.88	1.30	-0.84	0.94
<i>K and T</i>	-5.11	66.00	1.46	3.36	1.15	1.48
<i>L and T</i>	-0.76	2.27	-0.94	1.31	-3.06	23.33
<i>Latin America</i>						
<i>K and L</i>	-1.05	0.33	-0.52	3.22	-1.24	2.75
<i>K and T</i>	0.87	2.09	2.14	14.32	-0.20	9.78
<i>L and T</i>	-1.03	0.33	-0.94	2.23	-0.55	3.39
<i>Temperate region</i>						
<i>K and L</i>	-0.91	0.62	-1.01	0.46	-0.89	1.92
<i>K and T</i>	0.78	1.02	1.01	0.62	1.24	9.73
<i>L and T</i>	-0.83	0.73	-1.00	2.01	-1.03	3.97

have been land-saving and labor-using. Land-saving technology is usually associated with raising the productivity of the underlying land or resource base. Examples include new high-yielding seed varieties, improved fertilizers, herbicides, and pesticides, irrigation schemes, etc. Although it may be hard to draw definite conclusions, the elasticities suggest that outmigration from agriculture or slow growth of rural labor supply is not necessarily driven by advances in agricultural technology. Other factors, including higher expected returns to alternative economic activities, may be more important.

SUPPLY RESPONSE

Information contained in aggregate own price supply elasticities is important in its implication for resource adjustment and production in the face of policies which distort agricultural prices. If the elasticity is low, then policies which either tax or subsidize production have little effect on the level of production. Deadweight losses resulting from such policies are low.

If the elasticity is higher, then the cost associated with the distortionary policy is higher as well.

In his review of estimated own price supply elasticities, Peterson (1988) reported that most estimates range between 0.1 and 0.4. Peterson argued that these low estimates were a result of using times series data which overstated expected price variation. He advocated the use of cross-country data, arguing that they reflect the response to differences in average levels of expected prices. Peterson's estimated own price supply elasticity was 1.19, which is considerably higher than those he surveyed.

Based on Peterson's methodology, an aggregate supply elasticity can be discerned from the estimation of an aggregate production function. In equilibrium, the value of a factor's marginal product is equal to its marginal cost:

$$P_y \text{ MPP}_x = P_x \quad (19)$$

where P_y is the output price, P_x is the price of input x , and MPP_x is the marginal product of input x . Rearranging terms produces:

$$P_y/P_x = \frac{1}{\text{MPP}_x} \quad (20)$$

The reciprocal of the estimated marginal productivity of factor x equals the ratio of the output price to the price of x .⁹ Since production is modeled as a function of three factors, it is necessary to aggregate output/ input price ratios for each country. Letting i index factors and j index countries, define a relative output/input price ratio for factor i in country j as follows:

$$P_{ij} = \frac{\text{MPP}_{ij}}{\text{AVG}(\text{MPP}_i)} \quad (21)$$

Defining θ_i as the factor share of input i , the aggregate output/ input price ratio for country j is defined:

$$P_j = \sum_{i=1}^3 \theta_i P_{ij} \quad (22)$$

⁹ Peterson calculated the marginal productivity of a factor in the following way. He estimated an aggregate agricultural production function specified in Cobb–Douglas form:

$$Y = A * X_1^{b_1} * X_2^{b_2} \dots * X_n^{b_n}$$

The marginal productivity of an arbitrary factor such as X_1 is calculated as:

$$\text{MPP}_{x1} = A * b_1 * X_1^{(b_1-1)} * \bar{X}_2^{b_2} \dots * \bar{X}_n^{b_n}$$

where the bar above a variable refers to its mean value in the sample.

The output level is regressed on P_j and a constant. The elasticity is computed by multiplying the regression coefficient by the ratio of the mean values of output and the P_j .

We followed Peterson's methodology in calculating the supply elasticities. We indexed the production variables by dividing through the rural labor

TABLE 7

Regression results: supply elasticities

Region/variable	Agricultural production	Crop production	Livestock production
<i>Africa</i>			
Supply coefficient	1.15	2.81	1.70
Standard deviation	6.55	1.16	0.58
Coefficient <i>T</i> -value	0.18	2.42	2.92
<i>R</i> -squared	0.97	0.98	0.99
<i>F</i> -value	2,727	3,567	7,128
Calculated elasticity	0.15	0.70 *	1.35 *
<i>Arab Countries</i>			
Supply coefficient	111.41	69.68	49.21
Standard deviation	7.54	5.36	5.28
Coefficient <i>T</i> -value	14.77	13.01	9.31
<i>R</i> -squared	0.97	0.96	0.89
<i>F</i> -value	754	639	221
Calculated elasticity	6.66 *	7.12 *	11.12 *
<i>Asia</i>			
Supply coefficient	18.36	1.86	94.84
Standard deviation	8.00	2.47	9.30
Coefficient <i>T</i> -value	2.29	0.75	10.20
<i>R</i> -squared	0.95	0.84	0.98
<i>F</i> -value	668	183	1,849
Calculated elasticity	1.07 *	0.33	10.73 *
<i>Latin America</i>			
Supply coefficient	32.38	26.01	22.59
Standard deviation	9.82	7.90	8.08
Coefficient <i>T</i> -value	3.30	3.29	2.79
<i>R</i> -squared	0.95	0.92	0.98
<i>F</i> -value	1,223	679	2,926
Calculated elasticity	1.39 *	1.88 *	1.71 *
<i>Temperate region</i>			
Supply coefficient	798	289	790
Standard deviation	126	115	177
Coefficient <i>T</i> - value	6.31	2.51	4.46
<i>R</i> -squared	0.84	0.84	0.91
<i>F</i> -value	356	360	662
Calculated elasticity	6.32 *	5.17 *	7.31 *

* Significant at 0.01 level.

variable. Our elasticities therefore show the responsiveness of per capita production with respect to changes in the calculated output/input price ratio. We included in our regressions indicator (dummy) variables defined for each of the countries in the sample. These variables help to pick up fixed country effects not otherwise ascertainable in the regressions.

Table 7 shows the regression results, including the calculated elasticities. Thirteen of the 15 elasticities are statistically significant. Given the pooled cross-sectional times-series data set, we interpret our elasticities as representing adjustments occurring over the long term, that is, over 5 years. The elasticities indicate that per capita production is very responsive with respect to changes in the output/input price ratio.

This is especially true in the Arab countries and in the temperate region. The livestock elasticities tend to be higher than the crop elasticities. The lowest valued, significant elasticity of 0.70 for African crop production is still high relative to elasticities reported by Peterson in the 0.1–0.4 range.

Given the large degree of government involvement in most agricultural systems worldwide, the large elasticities imply that price distortions have likely had large effects on agricultural resource use and production. The welfare costs associated with the distortions have likely been high as well. The high elasticities also imply, however, that food shortages in LDC's may be less of a problem in the future if farm prices were allowed to increase.

CONCLUSION

It is well accepted that agriculture has become research and capital-intensive. A problem is that the increase and application of new technology has been unevenly distributed worldwide. LDC's in particular have not been able to absorb technical improvements as rapidly as the more developed industrialized countries. The basic problem is an insufficient degree of capital investment in LDC agricultural sectors. There exist a wide array of LDC sectoral and macroeconomic policies which have effectively taxed or discriminated against their agricultural sectors.

The first best way to address the LDC problem is to reform those policies which effectively discriminate against agriculture. A precondition for increased agricultural investment is to have in place a set of agricultural prices which fairly represent the opportunity cost of agricultural resources. As Krissoff et al. (1989) have shown, there are potential economywide gains from agricultural trade liberalization. These gains could increase investment potential for agricultural research, for the implementation of new techniques, and for the development of rural infrastructure.

The goal of this paper has been to empirically examine the role that capital accumulation plays in the growth of agricultural production poten-

tial. Implementation of the empirical model has involved the estimation of various translog aggregate production functions. Agricultural GDP, crop production, and livestock production have been estimated as functions of rural labor, arable land, and agricultural capital. The capital series has been constructed using an approach developed by Dadkhan and Zahedi (1986). Aggregate functions based on geographical groupings (Africa, Latin America, Arab and North Africa, Asia, and temperate region countries) provide the best statistical results from the estimation.

Estimation results show that capital accumulation is an important factor in the growth of agricultural growth potential, especially in livestock production. Even so, endowments of arable land and rural labor can be just as important, if not more so, to the potential for growth. This result tends to support the proposition that agriculture is still a resource based industry in which endowments of primary factors will be crucial for determining the course of agricultural development.

Estimation results support the conjecture that capital tends to save scarce land resources (substitute relationship) and use rural labor (complementarity relationship). Increasing use of capital in agriculture may therefore increase the demand for rural labor services. Outmigration from agriculture may not be a necessary reflection of technical change in that sector.

Results also indicate that aggregate agricultural supply is very responsive to changes in output/input price ratios. An implication is that price distortions likely have large effects on agricultural resource use and production. Agricultural production shortfalls in LDC's should be less of a problem in the future if farm prices are allowed to increase to world levels.

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