Staff Paper Series

Staff Paper P69-24 November 1969

Sources of Agricultural Productivity Differences Among Countries Resource Accumulation, Technical Inputs and Human Capital

By

Yujiro Hayami and V.W. Ruttan
Universiy of Minnesota

Department of Agricultural Economics

University of Minnesota
Institute of Agriculture
St. Paul, Minnesota 55108

Staff Paper P69-24 November 1969

SOURCES OF AGRICULTURAL PRODUCTIVITY DIFFERENCES AMONG COUNTRIES RESOURCE ACCUMULATION, TECHNICAL INPUTS AND HUMAN CAPITAL

Yujiro Hayami and V. W. Ruttan
University of Minnesota

The research on which this paper is based was financed through a grant from the Rockefeller Foundation.

Sources of Agricultural Productivity Differences Among Countries: Resource Accumulation, Technical Inputs and Human Capital*

BY YUJIRO HAYAMI AND V. W. RUTTAN **

The sources of productivity growth over time, and of productivity differences among countries and regions have emerged as a central unifying theme of growth theory and development economics. [1] In recent years a concensus seems to have emerged to the effect that productivity growth in the agricultural sector is essential if agricultural output is to grow at a sufficiently rapid rate to meet the demands for food and raw materials that typically accompanies urbanization and industrialization [1] [14] [17] [18]. Failure to achieve rapid growth in agricultural productivity can result either in the drain of foreign exchange or in shifts in the internal terms of trade against industry, and thus seriously impede the growth of industrial production. Failure to achieve rapid growth in labor productivity in agriculture can also raise the cost of transferring labor, and other resources, from the agricultural to the nonagricultural sector as development proceeds.

Extremely wide differences in agricultural productivity exist among countries. Agricultural output per worker in India is approximately one-fiftieth of that in the United States. Relatively few underdeveloped countries have achieved levels of output per worker one-fifth as high as in the United States. Furthermore, these differences have widened during the last decade [8] [10]. This lag in the rate of productivity growth in agriculture represents a serious constraint on economic growth in many developing economies.

Recent empirical research supports a classification of the sources of productivity differences, or of productivity growth, into three broad categories, (a) resource endowments, (b) technology, embodied in fixed or working capital, and (c) human capital, broadly conceived to include the education, skill, knowledge and capacity embodied in a countries population. Although this is clearly an oversimplification it does represent a substantial advance over the earlier emphasis on single key or strategic factors [7] [15] [16] [20].

Our analysis indicates that the three broad categories outlined above account for approximately ninty percent of the differences in labor productivity in agriculture between a representative group of Less Developed Countries (LDC's) and of Developed Countries (DC's). In this comparison the three factors are of roughly equal importance. When compared to the DC's of recent settlement (Australia, Canada, New Zealand and the United States) favorable resource endowments account for somewhat more than one third of the differences. Resource endowments is the major factor accounting for differences in labor productivity between the DC's of recent settlement and the older DC's. Nevertheless it seems apparent that the LDC's could, over time, achieve labor productivity levels in agriculture well over half as high as in the more recently settled DC's, roughly comparable to the levels achieved in the older DC's, through increased use of technical inputs supplied from the industrial sector and improvements in the quality of the labor force, even in the absence of substantial changes in man-land ratios.

I. The Method and the Data

The approach used in this study involves the estimation of a cross-country production function of the Cobb-Douglas type for thirty-eight developed and underdeveloped countries. [2] Differences in agricultural output per worker are accounted for by differences in the level of conventional and nonconventional inputs per worker, classified as (a) internal resource accumulation, (b) technical inputs supplied by the non-agriculture sector, and (c) human capital. [3]

Production functions were estimated for three different periods; 1955 (1952-56 averages), 1960 (1957-62 averages) and 1965 (1962-66 averages).[4] The variables used in the study included labor, land, livestock, fertilizer, machinery, education and technical manpower (see Appendix B for sources and definitions of the data). In summing up the effects of resource endowments, technology and human capital on productivity per worker, land and livestock serve as proxy variables for internal resource accumulations; machinery and fertilizer for technical inputs; and general and technical education in agriculture for human capital.

Land, being utilized for agricultural production can not be regarded as a mere gift of nature. It represents the result of previous investment in land clearing, reclamation, drainage, fencing and other development measures. Similarly livestock represents a form of internal capital accumulation. Thus, in our perspective, land and livestock represent a form of long term capital formation embodying inputs supplied primarily by the agricultural sector. [5] Both high inputs of land and of livestock per worker tend to be associated with high levels of labor and low levels of land per unit of output. In contrast fertilizer (as measured by the N + P_2O_5 + K_2O in commercial fertilizers) and machinery (as measured by tractor horsepower) represent inputs supplied by the industrial sector. Technical advances stemming from both public and private sector research and development are embodied in or complementary to these modern industrial inputs. Mechanical innovations are usually associated with larger inputs of power and machinery. Biological improvements, such as the innovations embodied in high yielding varieties, are typically associated with higher levels of fertilizer use. In this analysis these two industrial inputs represent proxies for the whole range of inputs which carry modern mechanical and bio-chemical technologies.

The proxies for human capital include measures of both the general educational level of the rural population and specialized education in the agricultural sciences and technology. Two alternative measures of the level of general education were attempted: (a) the literacy ratio and (b) the school enrollment ratio for the primary and secondary levels. Both sets of data are deficient in that they apply to the entire population and are not sensitive to differences in the quality of rural and urban education. Education in the agricultural sciences and technology was measured by the number of graduates from agricultural faculties at above the secondary level per ten thousand farm workers. These graduates represent the major source of technological and scientific personnel for public sector agricultural research and extension and for research, development and marketing in the private agribusiness sector.[6]

A critical assumption in this approach is that the technical possibilities available to agricultural producers in the different countries can be described by the same production function. Cross-section production functions, using individual countries or regions as observations, have been widely used. Cross-country aggregate production functions for the agricultural sector were first estimated by J. P. Bhattacherjee in 1953.[7] An aggregate agricultural production function similar to that used in this study, using states in the United States as observations was employed by Zvi Griliches in an attempt to account for the impact of research and education on agricultural output [7]. A. O. Krueger's recent efforts to estimate the contribution of factor endowment differentials to variations in per capita income employs the assumption that all countries are subject to a uniform production function [15].

In a recent paper R. R. Nelson has argued that the assumptions of a common production function "get in the way of understanding international differences in productivity - particularly differences between advanced and underdeveloped countries" [16, p. 1229]. Nelson's objections appear directed primarily to the empirical results obtained from use of relatively primitive two factor production functions, as in K. J. Arrow, H. B. Chenery, B. S. Minhas and R. M. Solow [2] where cross-country differences in value added per worker are related to the capital-labor ratio.[8] He insists, as a result of differential diffusion of new technology, that "at any given time one would expect to find considerable variation among firms with respect to the vintage of their technology, certainly between countries, but even within a country" [16, p. 1230].

We share the Nelson perspective. Agricultural producers in different countries, in different regions of the same country, and in different farms in the same region are not all on the same micro-production function. This reflects differences among producers in their ability to adopt new technology. More importantly, it is also the result of differential diffusion of agricultural technology, and, to an even greater degree, of differential diffusion of the scientific and technical capacity to invent and develop new mechanical, biological and chemical technology specifically adapted to the factor endowments and prices in a particular country or region. Furthermore, we view the generation of new technical knowledge in agriculture as endogenous. It is generated in response to growth of demand and changes in relative factor prices.

We hypothesize a system in which technical change occurs in response to changes in relative factor prices along the iso-product surface of a secular or "meta-production function." The full range of technological alternatives described by the meta-production function, which represents the envelope of all known and potentially available production "activities" and neoclassical production functions, is only partially available to individual producers in a particular country or agricultural region during any particular historical "epoch."[9] It is, however, potentially available to agricultural scientists and technicians.

We view the common or cross-country production function which we have estimated as a meta-production function. It is assumed that the invention and diffusion of a new "location specific" agricultural technology through the application of the concepts of physical, biological, and chemical science and of engineering, craft, and husbandry skills, is capable of making the factor productivities implicit in the cross-country production function available to producers in less developed countries. It is also assumed that the capacity of a country to engage in the necessary research, development and extension is measured by the two proxy variables for human capital, general education, and technical education in agriculture. It appears to us that this effort, and that of Griliches [7] and Krueger [15] are not inconsistent with the perspective presented by Nelson in his criticism of the empirical results obtained from two factor cross-country production functions.

The production function employed in this study was of the Cobb-Douglas type. It was used mainly because of its ease in manipulation and interpretation. A previous test, however, was not inconsistent with the assumption of unitary elasticity of substitution implicit in the Cobb-Douglas production function [9]. The ordinary least squares estimation procedure was used. The possibility of simultaneous equation bias seems small because all inputs, except fertilizer, are measured in stock terms and can be treated as predetermined. In a few cases, however, the method of instrumental variables was tried to see if any different inferences might be drawn. The assumption of a common production function among countries is a testable hypothesis. Our attempt to conduct such a test seems to imply that the data used in this study are too crude to be employed in the test (see Appendix A).

II. Estimation of Production Function on 1960 Data

We conducted an especially detailed analysis for 1960 because of (a) better comparability of output data and (b) availability of data for the number of farms in this year.[10] Table 1 presents the estimates of the unrestricted Cobb-Douglas production function on the 38 cross-country data (Surinam was dropped from the sample in the estimation of Regressions 4, 5, 9 and 10 because of the lack of technical education data). The estimation was made both on per-farm data (output and conventional inputs deflated by the number of farms) and on national aggregate data. The results from these two sets of data are not sufficiently different to lead to different inferences regarding the agricultural production structures among countries.

Considering the crudeness of data, the levels of statistical significance of the estimated coefficients seem satisfactory in most cases (except the coefficients for machinery in Regression 4, 9, and 9IV and the coefficients for land in Regression 4IV and 5IV). The coefficients stay fairly stable when nonconventional variables are added or subtracted, though the coefficients for labor and livestock tend to move opposite to the coefficient for machinery. The results of estimation by the method of instrumental variables (denoted as IV) compared with the least square estimates provide no <u>prima facie</u> evidence against the use of least squares.

Attempts to include other variables, e.g., the ratio of irrigation land to total land area and the ratio of cropland to pasture land, were tried in an attempt to adjust for differences in the quality of land input; but it turned out that the coefficients for such variables are either negative or nonsignificant.[11]

Table 1. Estimates of agricultural production function on cross-country data, 1960

	Per farm basis						
Regression number	(1)	(2)	(3)	(4)	(5)	(4IV)	(5IV)
Sample size	38	38	38	37	37	37	37
Labor	0.374 (0.120)	0.413 (0.124)	0.421 (0.123)	0.474 (0.120)	0.431 (0.123)	0.474 (0.119)	0.433 (0.120)
Land	0.100 (0.075)	0.109 (0.075)	0.109 (0.074)	0.133 (0.070)	0.121 (0.073)	0.064 (0.068)	0.048 (0.070)
Livestock	0.165 (0.101)	0.162 (0.101)	0.163 (0.100)	0.227 (0.096)	0.211 (0.100)	0.225 (0.095)	0.207 (0.099)
Fertilizer	0.186 (0.056)	0.167 (0.057)	0.151 (0.060)	0.138 (0.062)	0.151 (0.679)	0.086 (0.037)	0.094 (0.039)
Machinery	0.164 (0.063)	0.139 (0.066)	0.145 (0.063)	0.031 (0.072)	0.084 (0.069)	0.085 (0.067)	0.140 (0.060)
General education							
: Literacy ratio		0.323 (0.197)		0.398 (0.198)		0.415 (0.194)	
: Sch. enrollment ratio			0.366 (0.263)		0.301 (0.267)		0.373 (0.247)
Technical education				0.153 (0.061)	0.105 (0.059)	0.153 (0.061)	0.101 (0.058)
Coef. of det. (adj.)	0.903	0.904	0.906	0.920	0.912	0.920	0.915
S.E. of est.	0.140	0.139	0.138	0.128	0.134	0.127	0.132
Sum of conventional coefficients	0.989 (0.097)	0.990 (0.097)	0.989 (0.096)	1.003 (0.089)	0.998 (0.093)	0.934 (0.091)	0.922 (0.096)

Equations linear in logarithm are estimated by least squares (Regression 1-5) and by instrumental variable method using lagged fertilizer input as the instrumental variable (Regression 4IV-5IV). The standard errors of coefficients are in parentheses. See Appendix B for sources of data.

Table 1 (cont'd) Estimates of agricultural production function on cross-country data, 1960

	National aggregate basis						
Regression number	(6)	(7)	(8)	(9)	(10)	(9IV)	(10IV)
Sample size	38	38	38	37	37	37	37
Labor	0.342 (0.066)	0.378 (0.075)	0.389 (0.079)	0.458 (0.080)	0.416 (0.083)	0.464 (0.077)	0.420 (0.078)
Land	0.095 (0.067)	0.103 (0.068)	0.102 (0.068)	0.128 (0.066)	0.113 (0.069)	0.135 (0.067)	0.122 (0.070)
Livestock	0.187 (0.099)	0.182 (0.099)	0.180 (0.099)	0.230 (0.095)	0.216 (0.100)	0.213 (0.095)	0.200 (0.099)
Fertilizer	0.176 (0.054)	0.161 (0.056)	0.151 (0.059)	0.129 (0.064)	0.141 (0.069)	0.134 (0.063)	0.150 (0.069)
Machinery	0.147 (0.058)	0.127 (0.062)	0.136 (0.059)	0.034 (0.071)	0.087 (0.066)	0.039 (0.069)	0.086 (0.064)
General education							
: Literacy ratio		0.289 (0.194)		0.385 (0.200)		0.394 (0.204)	
: Sch. enrollment ratio			0.282 (0.267)		0.279 (0.267)		0.216 (0.274)
Technical education				0.148 (0.062)	0.100 (0.059)	0.133 (0.064)	0.088 (0.059)
Coef. of det. (adj.)	0.954	0.954	0.954	0.947	0.942	0.948	0.943
S.E. of est.	0.135	0.135	0.135	0.127	0.133	0.127	0.131
Sum of conventional coefficients	0.947 (0.037)	0.951 (0.037)	0.958 (0.037)	0.979 (0.041)	0.973 (0.043)	0.985 (0.042)	0.978 (0.043)

Equations linear in logarithms are estimated by least squares (Regressions 6-10) and by instrumental variable method using lagged fertilizer input as the instrumental variable (Regression 9IV-10IV). The standard error of coefficients are in parentheses. See Appendix B for sources of data.

Plausibility of the estimates may be checked by comparison with the results of earlier attempts to estimate aggregate production functions in various countries. Bhattacharjee [3] obtained aggregate production elasticities for his cross-country production function (including only conventional variables) centered on 1950 of around 0.30 for labor; 0.34 to 0.43 for land; and 0.28 for fertilizer. The coefficients for livestock and tractors were not significant at commonly accepted levels. The Bhattacharjee results indicate lower production elasticities for land and fertilizer than the results obtained in our study. It would appear that our model is somewhat better specified, in that we obtained statistically meaningful coefficients for livestock and machinery as well as for the two proxy variables for human capital.

The aggregate production elasticities of U.S. agriculture were estimated by Griliches as 0.4 to 0.5 for labor; 0.1 to 0.2 for land, fertilizer and machinery; 0.3 to 0.5 for education; 0.04 to 0.1 for research and extension [7]. It is rather surprising that the Griliches' estimates, despite the completely different nature of the data used, coincide so well with the ones in this study. An interesting finding of the Griliches' study is that in U.S. agriculture the percentage increase in education has the same output effect as percentage increase in labor. The same inference was also drawn from this cross-country study. [12]

The production elasticities estimated for Japanese agriculture by Yuize in value-added terms are in the ranges of 0.4 to 0.6 for labor and 0.2 to 0.4 for land [21]. Such figures are consistent with the estimates in this study since the ratio of value added to gross output was around 0.7 in Japanese agriculture in the period when Yuize's study was made [22]. In the less developed countries we do not have comparable estimates of the aggregate agricultural production function. T. W. Schultz has, however, inferred from the impact of the 1918-19 influenza epidemic that the production elasticity of labor in Indian agriculture was 0.4. This is consistent with our estimates [8, pp. 63-70]. Such consistency with other studies gives support to the results of estimation in this study.

Judging from the sums of coefficients of conventional inputs, compared with the standard errors of those sums (in the parentheses given below the sums of coefficients), constant returns seem to prevail both in farm firm level and in national aggregate level. The constant returns at farm firm level may explain the existence of farms of extremely different sizes producing the same commodities. The constant returns at national aggregate level might be one of the distinctive characteristics of agricultural production and, if so, would have important implications on the inter-sectoral investment priorities for national economic development.

III. Stability of Production Function Over Time

In this section the stability of the agricultural production function over time is tested on the 1955, 1960 and 1965 cross-country sample. Because comparable data on the number of farms were not available for 1955 and 1965, we assumed the linear homogeneity in the Cobb-Douglas production function and regressed output per capita (per male worker) on conventional inputs per capita and on nonconventional inputs. The linear homogeneity assumption is based on the information contained in Table 1. In order to make the data comparable among years we restricted the countries included in the sample to 36 (Mauritius and Surinam were dropped from the sample for lack of labor data).

The results of our estimations are summarized in Table 2. Comparing the estimates of the per-capita production function with those of the unrestricted form in Table 1 (Regressions 11 and 12 compared with Regressions 4 and 5 or 9 and 10), we see that the land coefficients become smaller and the livestock coefficients become larger. Differences in the two sets of estimates are, however, not so large as to imply different conclusions. The production parameters seem largely stable over time. The null hypothesis of the equality of the production coefficients among 1955, 1960 and 1965 is accepted (the F-statistics calculated from Regressions 12, 13, 14 and 17 is only 0.41).

Table 2 Extimates of agricultural production function on cross-country data, 1955-60-65

	Per capita basis						
Regression number	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Year	1960	1960	1955	1965	1955-60	1960-65	1955-60-65
Sample size	36	36	36	36	72	72	108
Land	0.108 (0.066)	0.090 (0.068)	0.088 (0.075)	0.079 (0.077)	0.089 (0.048)	0.082 (0.049)	0.081 (0.041)
Livestock	0.278 (0.098)	0.267 (0.102)	0.321 (0.107)	0.255 (0.107)	0.296 (0.071)	0.260 (0.070)	0.282 (0.058)
Fertilizer	0.116 (0.062)	0.119 (0.068)	0.131 (0.066)	0.148 (0.087)	0.128 (0.045)	0.134 (0.052)	0.138 (0.040)
Machinery	0.039 (0.069)	0.097 (0.064)	0.048 (0.055)	0.124 (0.067)	0.070 (0.040)	0.116 (0.044)	0.095 (0.033)
General education : Literacy ratio	0.419 (0.192						
: Sch. enroll-ment ratio		0.384 (0.261)	0.295 (0.199)	0.443 (0.355)	0.260 (0.152)	0.384 (0.201)	0.282 (0.139)
Technical education	0.149 (0.060)	0.096 (0.057)	0.142 (0.056)	0.064 (0.053)	0.121 (0.038)	0.076 (0.036)	0.093 (0.030)
Dummy: 1950					0.001 (0.029)		-0.002 (0.030)
1965						-0.013 (0.031)	0.010 (0.031)
Coef. of det. (adj.)	0.920	0.913	0.907	0.902	0.917	0.913	0.914
S.E. of est.	0.123	0.128	0.123	0.144	0.121	0.131	0.127
Implicit coefficient of labor	0.459	0.427	0.412	0.394	0.417	0.408	0.404

Equations linear in logarithm are estimated by least squares. The standard errors of coefficients are in parentheses. See Appendix B for sources of data.

IV. Accounting for Productivity Differences

The results obtained from estimation of the agricultural production function in the previous sections will, in this section, be used to account for inter-country differences in labor productivity (output per male worker) in agriculture in 1960.

Since our production function is now assumed to be linear homogeneous in the Cobb-Douglas form, the percentage difference in output per worker can be expressed in the sum of percentage differences in conventional inputs per worker and in nonconventional inputs weighted by the production elasticities. Based on the results shown in Table 1 and Table 2 the following set of production elasticities was adopted: 0.40 for labor, 0.15 for land, 0.20 for livestock, 0.15 for fertilizer, 0.10 for machinery, 0.40 for education, and 0.10 for research and extension. Only the school enrollment ratio was used as the education variable in this accounting, but the results would have been essentially the same if the literacy ratio had been used.

Two alternative sets of results are presented. The first set involves group comparisons between LDC's and DC's. The second set involves individual comparisons of selected LDC's and DC's with the United States.

Group Comparisons

The sources of differences in labor productivity between eleven LDC's and thirteen DC's (Case 1); nine older DC's (Case 2); and four DC's of recent settlement are presented in Table 3. The countries classified as LDC's, for the purposes of this comparison, all had per-capita income of less than 350 U.S. dollars and more than 35 percent of their labor force engaged in agriculture. The countries classified as DC's had per-capita income higher than 700 U.S. dollars and less than 30 percent of the labor force engaged in agriculture. Countries falling between these criteria are not included in the comparisons presented in Table 3.

The difference in average agricultural output per worker between the eleven LDC's and the thirteen DC's was 85.5 percent; the difference between the eleven LDC's and the nine older DC's was 78.9 percent; and the difference between the eleven LDC's and the four DC's of recent settlement was 92.6 percent. The six variables included in the production function accounted for 90, 84 and 91 percent of the difference in agricultural output per worker between the LDC's and the three DC's groups.

In the comparison between the eleven LDC's and the thirteen DC's (Case 1) each generalized category, internal resource accumulation (land and livestock), technical inputs from the industrial sector (fertilizer and machinery) and human capital (general and technical education in agriculture) account for approximately one-third of the explained difference in labor productivity.

The main difference between Case 1 and the other two cases is the amount of the difference explained by land. Differences in resource accumulation account for only five percent of the difference in labor productivity between the LDC's and the older DC's. This implies that it should be feasible for the LDC's to achieve levels of productivity per worker roughly equivalent to the labor productivity levels achieved by workers in the older DC's, - that is, roughly four times as high as

Table 3 Accounting of difference in labor productivity in agriculture between developed countries (DC) and less developed countries (LDC) as per cent of the labor productivity of DC

	Case 1 (13 DC's)		Case 2 (9 DC's)		Case 3 (4 DC's)	
	%	Index	%	Index	%	Index
Difference in output per male worker as per cent	85.5	(100)	78.9	(100)	92.6	(100)
Percentage of difference explained						
Total	77.2	(90)	65.9	(84)	84.6	(91)
Resource accumulation (Land and livestock)	28.0	(33)	17.7	(22)	33.2	(36)
Technical inputs (Fertilizer and machinery)	24.1	(28)	24.0	(31)	24.3	(26)
Human capital (General and technical education)	25.1	(29)	24.1	(31)	27.1	(29)
Land	11.8	(14)	4.3	(5)	14.7	(16)
Livestock	16.2	(19)	13.4	(17)	18.5	(20)
Fertilizer	14.3	(17)	14.2	(18)	14.4	(15)
Machinery	9.8	(11)	9.8	(13)	9.9	(10)
General education	16.8	(19)	16.5	(21)	18.2	(20)
Technical education	8.3	(10)	7.8	(10)	8.9	(10)

Inside of parentheses are percentages with output per worker differences set equal to 100.

DC: Australia, Belgium, Canada, Denmark, France, Germany, Netherlands, New Zealand, Norway, Sweden, Switzerland, UK, USA.
LDC: Brazil, Ceylon, Colombia, India, Mexico, Peru, Philippines, Syria, Taiwan, Turkey, UAR.
Case 1 includes all DC's; Case 2 excludes Australia, Canada, New Zealand and USA from DC's;
Case 3 includes only the four DC's excluded in Case 2.

Accounting formula:

$$\frac{Y_d - Y_l}{Y_d} = 0.15\left(\frac{a_d - a_l}{a_d}\right) + 0.20\left(\frac{s_d - s_l}{s_d}\right) + 0.15\left(\frac{f_d - f_l}{f_d}\right) + 0.10\left(\frac{m_d - m_l}{m_d}\right) + 0.40\left(\frac{E_d - E_l}{E_d}\right) + 0.10\left(\frac{U_d - U_l}{U_d}\right)$$

where y, a, s, f, m, are respectively output, land livestock, fertilizer, machinery per male worker; E and U are respectively the general education (school enrollment ratio) and the technical education variable; lower case letter d denotes DC and l denotes LDC.

present LDC levels and well over half the level outlined by the DC's of recent settlement. The critical elements in achieving such increases in labor productivity is the supply of modern industrial inputs by which the new technology is carried and the investment in general education and in research and extension which raises the capacity to develop and adopt a more productive technology.

Comparison of Case 2 and Case 3 results does indicate that resource endowments, particularly land, do represent a serious barrier to efforts of both the LDC's and the older DC's to achieve levels of output per worker comparable to the levels currently enjoyed in the more recently settled DC's. This is the first time, to our knowledge, that the economic advantage of the favorable resource endowments in these countries has been demonstrated quantitatively.

Individual Comparisons

The individual country comparisons presented in Table 4 were developed in order to provide somewhat deeper insight into the sources of differences in labor productivity between different "ideal type" DC's and LDC's and the United States. In general the results are consistent with the group comparisons.

In the four underdeveloped countries - India, Philippines, United Arab Republic and Columbia - internal resource accumulation account for approximately one-third and technical inputs roughly one-fourth of the differences. Human capital accounts for more than one-third of the difference between the U.S. and India, the United Arab Republic, and Columbia. In the Philippines, which has achieved a relatively high level

Table 4. Accounting of labor productivity differences in agriculture of selected countries from the U.S. as per cent of U.S. labor productivity, 11 selected countries

Country		Difference in output per worker from U.S. as percent of U.S.	Percentage of difference explained by			
			Total	Resource accumulation (land and livestock)	Technical inputs (fertilizer and machinery)	Human capital (general and technical education)
LDC						
Asia:						
Deficit:	India	97.7	97.7	33.2	25.0	39.5
		(100)	(100)	(34)	(26)	(40)
Surplus:	Philippines	95.8	77.2	33.7	24.3	19.2
		(100)	(81)	(35)	(26)	(21)
Africa:	UAR	95.5	93.3	34.1	24.7	34.5
		(100)	(98)	(36)	(26)	(36)
Latin America:	Colombia	89.2	86.0	27.3	24.7	34.0
		(100)	(96)	(30)	(28)	(38)
Europe:						
Exporter:	Denmark	59.3	50.5	23.2	13.7	13.6
		(100)	(85)	(39)	(23)	(23)
	Netherland	57.8	53.0	27.4	15.9	9.7
		(100)	(92)	(47)	(28)	(17)
Importer:	U.K.	52.7	49.2	20.4	13.5	15.3
		(100)	(93)	(39)	(25)	(29)
Self-sufficient:	France	61.6	61.5	27.4	16.9	17.2
		(100)	(100)	(45)	(27)	(28)
Japan		88.9	64.8	34.2	22.5	8.1
		(100)	(73)	(39)	(25)	(9)
Pastoral farming						
Less developed:	Argentina	59.8	46.4	0.2	24.3	21.9
		(100)	(78)	(0)	(41)	(37)
Developed:	New Zealand	-52.8	-37.6	-43.3	2.8	2.9
		(100)	(71)	(82)	(-5)	(-6)

Inside of parentheses are percentages with output per worker differences set equal to 100.

of schooling and produces a relatively large number of agricultural college graduates, human capital explains less than one-fourth of the productivity difference. The contrast between India and the Philippines in this respect is quite striking.

In the comparisons between the countries of Europe and the United States, differences in internal resource accumulation represent the most significant source of difference in labor productivity. Increases in the use of technical inputs and improvements in the quality of human capital can bring labor productivity in the several European countries closer to the U.S. level. Nevertheless it seems apparent that major advances in labor productivity in European agriculture toward U.S. level is dependent on the absorbtion of a higher percentage of the agricultural labor force into the nonagricultural sector. The Japanese case is similar to the European, except that Japan has moved further toward the exhaustion of productivity differentials associated with investment in education and research. In our judgment the model underestimates the significance of the land constraint in the Japanese case. Without significant increase in land area per worker it would be impossible for Japanese agriculture to increase technical inputs (especially machinery) to the U.S. level.

The two pastoral farming cases are of particular interest. In spite of low levels of technical inputs labor productivity in Argentina is roughly comparable to that in Europe. This is due almost entirely to a favorable man-land ratio comparable to that in the U.S. Argentina has, as a result of underinvestment in technology and human capital, failed to fully exploit its favorable man-land ratio. New Zealand, in contrast, has achieved a level of labor productivity well above the U.S. level (the highest in the world) by complementing its favorable resource endowments with high levels of technical inputs and investment in education and research.

The results obtained in both group and individual comparisons are somewhat different than those obtained by Krueger [15]. Using a different methodology, Krueger found that human capital explained more than half the difference in income levels between the United States and a group of less developed countries. This is in contrast to our studies in which human capital explains approximately one-third of the difference in labor productivity. Krueger's results apply to the entire economy and ours to only the agricultural sector. It seems reasonable to expect that resource endowments would be of relatively greater significance in the agricultural sector than in the total economy. We see, therefore, no inconsistency between our results and those obtained by Krueger. In general the consistency between the results presented in Tables 3 and 4, combined with our general knowledge of the economies being studied, strengthens our confidence in the methodology employed in this study.

V. Implications for Agricultural Development Strategy

The implications of this analysis for agricultural development strategy in the less developed countries has both encouraging and discouraging aspects. It is clear that output per worker in the several LDC's can be increased by several multiples while land area per worker remains constant or even declines slightly. To achieve increases of this magnitude will require substantial investment (a) in rural education and (b) in the physical, biological and social sciences required for the technical and institutional infrastructure needed for the invention, development and extension of a more efficient agricultural technology. It will also require the allocation of substantial resources to the production of the technical inputs supplied by the industrial sector, by which new technology is carried into agriculture. By and large these changes achieve the higher levels of output per worker through increases in output per unit area.

A more discouraging aspect of this analysis is that in order to achieve levels of labor productivity comparable to the levels achieved in the DC's of recent origin it will be necessary to complement those technical changes designed to increase output per unit area with technologies that reduce the labor input per unit area. Significant reduction in labor input per unit area are likely to occur, however, only in those economies in which urban-industrial development is sufficiently advanced to absorb not only the growth in the rural labor force but also to permit a continuous reduction in employment in rural areas [5] . It should be noted that this has occurred in Japan only since World War II. In most LDC's it seems likely that the agricultural labor force will continue to expand more rapidly than the nonagricultural demand for labor from rural areas.

The implications for agricultural development strategy for most less developed countries seems relatively clear. An attempt must be made to close the gap in the level of modern industrial inputs and in education and research. Agricultural surpluses generated by closing the gap, over and above the amount necessary to maintain the growth of agricultural productivity, must be used to finance industrial development.[13]

Maintenance of the rate of growth of agricultural productivity can be expected to impose a substantial drain on the savings that can be generated from the agricultural surpluses. Initially a substantial component of industrial capacity must be designed to provide technical inputs for the agricultural sector. Substantial investment will be needed to create the institutional infrastructure to improve general education in rural areas and to produce the technical and scientific manpower needed to bring about technical changes in agriculture. Investment in land development, such as irrigation and drainage, will also be necessary in a number of countries in order to obtain a full return from the new biological and chemical technology.

If successful, the effort would, over time, result in a rate of growth in the nonagricultural labor force sufficient to permit a reduction in the agricultural labor force and a rise in labor productivity toward the levels of the DC's of recent settlement. Clearly the process outlined here is inconsistent with the low cost route to agricultural development that seemed to be opened up by the dual economy models which have dominated much of the theoretical discussion of agricultural development during the last decade.

REFERENCES

1. Irma Adelman and C. T. Morris, "An Econometric Model of Socio-Economic and Political Change in Underdeveloped Countries," Amer. Econ. Rev., Dec. 1968, 58, 1184-218.

2. K. J. Arrow, H. B. Chenery, B. S. Minhas and R. M. Solow, "Capital-Labor Substitution and Economic Efficiency," Rev. Econ. Stat., Aug. 1961, 43, 225-50.

3. J. P. Bhattacharjee, "Resource Use and Productivity in World Agriculture," J. Farm Econ., Feb. 1955, 37, pp. 57-71.

4. Murray Brown, On the Theory and Measurement of Technological Change, Cambridge 1966, pp. 43-62.

5. Folke Dovring, "The Share of Agriculture in a Growing Population," Mo. Bull. Agric. Econ. and Statist., (FAO) Aug.-Sept. 1959, 8, 1-11.

6. M. J. Flanders, "Agriculture Versus Industry in Development - Policy: The Planner's Dilemma Re-examined," J. Develop. Studies, April 1968, 5, 171-89.

7. Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," Amer. Econ. Rev., Dec. 1964, 54, 961-74.

8. Yujiro Hayami, "Sources of Agricultural Productivity Gap Among Selected Countries," Amer. J. Agric. Econ., Aug. 1969, 51, 564-75.

9. ____________, "On the Use of the Cobb-Douglas Production Function in the Cross-country Analysis of Agricultural Production," Amer. J. Agric. Econ., (forthcoming).

10. ____________, and Kinuyo Inagi, "International Comparison of Agricultural Productivities," The Farm Economist, 11 (No. 10) 1969, 1-13.

11. ____________, and V. W. Ruttan, "Factor Prices and Technical Changes in Agricultural Development: The United States and Japan, 1880-1960," Department of Agricultural Economics, University of Minnesota, Staff Paper 69-19, Aug. 1969, mimeo.

12. J. R. Hicks, Capital and Growth, Oxford 1965.

13. Shigeru Ishikawa, Economic Development in Asian Perspective, Tokyo 1968.

14. D. W. Jorgenson, "The Development of a Dual Economy," The Econ. J., June 1961, 71, 309-34.

15. A. O. Kruegar, "Factor Endowments and Per Capita Income Differences Among Countries," The Econ. J., Sept. 1968, 78, 641-59.

16. R. R. Nelson, "A Diffusion Model of International Productivity Differences in Manufacturing Industry," Amer. Econ. Rev., Dec. 1968, 58, 1219-48.

C. H. Fei, "A Theory of Economic Development,"
ept. 1961, 51, 533-64.

n Stage Themes, Dual Economy Models, and Agri-
Policy, Publication No. AE 1968/2, Univ.

ductivity and Technical Change, Cambridge 1960.

sforming Traditional Agriculture, New Haven 1964.

gyo ni okeru Kyoshiteki Seisankansu no Keisoku (The Aggregate Production Function in Agriculture)," Nogyo Sogo Kenkyu, Oct. 1964, 18, 1-54.

22. Japan, Ministry of Agriculture and Forestry, Nogyo oyobi Nokano Shakai Kanjo 1967, (Social Accounts of Agriculture and Farm Households) Tokyo 1968.

FOOTNOTES

*Minnesota Agricultural Experiment Station Scientific Journal Paper Series 69- . The research on which this paper is based was financed through a grant from the Rockefeller Foundation.

**Yujiro Hayami is associate professor, Department of Economics, Tokyo Metropolitan University and visiting associate professor, Department of Agricultural Economics, University of Minnesota. Vernon W. Ruttan is professor and head of department, Department of Agricultural Economics, University of Minnesota. The authors are indebted to Miss Sachiko Yamashita and Mrs. Barbara Miller for computational assistance in the preparation of this paper.

1 Hicks [12] has suggested that growth theory and development economics have no connection. This view would seem to be invalid in view of Hicks' own criteria. See Krueger [15, p. 656] .

2 Countries included are: Argentina, Austria, Australia, Belgium, Brazil, Canada, Ceylon, Chile, Colombia, Denmark, Finland, France, Germany, Greece, India, Ireland, Israel, Italy, Japan, Mauritius, Mexico, Netherlands, New Zealand, Norway, Peru, Philippines, South Africa, Spain, Surinam, Sweden, Switzerland, Syria, Taiwan, Turkey, U.A.R., U.K., U.S.A., and Venezuela.

3 For a report on a preliminary attempt see Hayami [8] .

4 It seems more consistent to have averages of 1953-57, 1958-62 and 1963-67, but the original estimates of agricultural output are of 1957-62 averages (see [10]) and, when we tried to extend the output series from 1958-62 to 1955 and 1965 by the index of agricultural production of FAO it was only available until 1966.

5 Perennial plants belong to the same category of inputs as livestock; but they are not included due to the lack of data.

6 In a sense this variable may be superior as the proxy for the level of research and extension than the "state average of public expenditure on research and extension per farm" used in the Griliches' study [7], because our variable may possibly reflect the research and extension activities in the private sector as well as in the public sector.

7 The study by Bhattacharjee [3] was published in 1956. It was based on his Ph.D. thesis completed in 1953.

8 For a review of the literature on the CES production function and an evaluation of its advantages and limitations see Murray Brown [4] .

9 In the <u>short run,</u> in which substitution between capital and labor is circumscribed by the rigidity of existing capital and equipment, production relationships are best described by an activity with relatively fixed factor-factor and factor-product ratios. In the <u>long run</u>, in which the constraints exercised by existing capital disappears and is replaced by the fund of available technical knowledge,

including all alternative feasible factor-factor and factor-product combinations, production relationships can be adequately described by the neoclassical production function. In the secular period of production, in which the constraints given by the available fund of technical knowledge is further relaxed to admit all potentially discoverable knowledge, production relationships can be described by a meta-production function which describes all potentially discoverable technical alternatives. The meta-production function can be regarded as the envelope of neoclassical production functions. Although the term is not employed, the meta-production function concept is implicit in the work of Brown [4] and of Salter [19] . We have discussed the rationale for the meta-production function concept and the role of induced innovation in Japanese and U.S. agricultural development in greater detail elsewhere [11]. The elasticity of substitution among factors increases continuously as the time period increases from the short run to the secular period.

10 Original data estimated for 1960, and the data for 1955 and 1960 are the extrapolation by the FAO's production index (see Appendix B). The 1960 World Census of Agriculture provides for a large number of countries the data of the number of farms, but the comparable data are but scattered for 1955 and 1960.

11 This does not necessarily mean that such variables have no significant influence, but rather it means that the presently available data are too crude to estimate the influences of such variables.

12 The F-statistics calculated for the equality of the labor and education coefficients are: 0.53 for Regression 2, 0.003 for Regression 3, 0.08 for Regression 4, 0.13 for Regression 5, 0.89 for Regression 7, 0.12 for Regression 8, 0.07 for Regression 9, 0.25 for Regression 10.

13 Ishikawa has suggested that achievement of national agricultural output and productivity objectives may, in some developing countries, require a net flow of savings from the non-agricultural to the agricultural sector [13]. The possibility has been such a shock to some students of development economics that they recommend a "development without agriculture" policy [6].

Appendix A. Estimation of Production Function for Different Groups of Countries: A Failure Example

A basic assumption in this study is that farmers in different countries are facing the same production function. In order to test this assumption, the production function was estimated for different groups of countries, DC and LDC. The estimation was tried for various groupings for DC and LDC, but the results are all implausible with most of the coefficients statistically nonsignificant or negative in sign. A failure example is presented in Table A which summarizes the results based on the same classification of countries as used in the analysis of Table 3. Other classifications produced more or less equally bad results. It seems that measurement errors in our observations (especially of nonconventional variables) are too large to make it possible to estimate the influences of variables for the groups of countries within which the ranges of data variations are relatively small. The basic assumption, is, therefore, not testable on the presently available data. All we can claim is that differences in agricultural productivity among countries can be explained well with this assumption.

Table A. Estimates of agricultural production function on cross-country data by classifications in terms of the levels of economic development, 1955-60-65 sample combined, per capita basis

Classification		DC	LDC	Other
Sample size		39	33	36
Land		0.049 (0.053)	0.179 (0.670)	0.130 (0.131)
Livestock		0.492 (0.108)	-0.021 (0.092)	-0.004 (0.169)
Fertilizer		-0.262 (0.136)	0.229 (0.051)	-0.138 (0.078)
Machinery		0.065 (0.565)	0.108 (0.051)	0.285 (0.101)
General education (Sch. enrol. ratio)		1.163 (0.489)	0.050 (0.143)	0.294 (0.453)
Technical education		0.096 (0.066)	-0.002 (0.027)	-0.207 (0.100)
Dummy	1960	0.048 (0.031)	-0.022 (0.038)	-0.001 (0.062)
	1965	0.112 (0.038)	-0.058 (0.042)	-0.033 (0.074)
Coef. of det. (adj.)		0.908	0.812	0.634
S.E. of est.		0.074	0.086	0.140
Implicit coefficient, of labor		0.656	0.505	0.727

Equations linear in logarithm are estimated by least squares. The standard errors of coefficients are in parentheses.

Classification of countries is the same as in Table 3.

Appendix B. Basic Data

In principle, flow variables (output and fertilizer) are measured as the averages for 1952-56, 1957-62, and 1962-66 respectively for 1955, 1960, and 1965, and stock variables (labor, land and machinery) are measured at those specified years. More detailed explanations may be obtained upon request.

Agricultural output: Agricultural output net of seeds and feed in thousand Wheat Units (Wheat Unit is equivalent to one ton of wheat); 1957-62 data in Hayami and Inagi [10]; 1952-56 and 1962-66 data are extrapolated from 1957-62 data by FAO index of agricultural production (FAO, *Production Yearbook*, various issues).

Labor: Number of male workers active in agriculture in thousands; Converted from the number of male workers active in agriculture, forestry and fishing in ILO, *Yearbook of Labor Statistics*, various issues (supplemented by FAO, *Production Yearbook*). See the method of conversion in [10].

Land: Total area of agricultural land in thousand hectares; FAO, *Production Yearbook*, various issues.

Livestock: Aggregate of various kinds of livestock in thousand livestock units; numbers of livestock in FAO, *Production Yearbook*, converted to livestock units by the following factors: 1.1 for camel; 1.0 for buffalo, horses and mules; 0.8 for cattle and asses; 0.2 for pigs; 0.1 for sheep and goats; 0.01 for poultry.

Fertilizer: Sum of N, P_2O_5 and K_2O in thousand metric tons in commercial fertilizers consumed; FAO, *Annual Review of Fertilizers*, various issues.

Machinery: Tractor horsepower in thousand hp.'s; see [10] for the process of estimation.

Number of farms: Number of agricultural holdings in thousands; data from FAO's report on the 1960 World Census of Agriculture except Chile--Committee on Inter-American Development, Land Tenancy and Socio-economic Development, Santiago 1966, p. 42; France---interpolated from 1955 and 1963 data in Ministere de l'agriculture, Enquête communautaire sur la structure des exploitations agricole en 1967, 1968, p. 7; India---Directorate of Economics and Statistics, Ministry of Food, Agriculture, Community Development and Cooperation, Indian Agriculture in Brief, 1967, p. 65; Israel and Syria---Marion Clawson and others, Agricultural Potential of the Middle East, Part I and II, Resources for the Future, Inc. (mimeo) 1969, pp. 8-16; Mauritius---Number of sugar planters in J. E. Mead, The Economic and Social Structure of Mauritius, London 1961, p. 75; Switzerland---Exterpolated from 1950 and 1955 data in Dritter Bericht der Bundesversammlung über die Lage der Schweizerischen Landwirtschaft und die Agrarpolitik des Bundes, Berne 1965, p. 6; UAR---M.M. El-Kammash, Economic Development in Egypt, New York 1968, p. 260.

Education(Literacy ratio): Literacy ratio in percent; UNESCO, World Literacy in Mid-Century, 1957, p. 38-44.

Education (School enrollment ratio): Ratio of school enrollments in the primary and secondary schools in percent, adjusted for differences in the school system, averages of three years in five year intervals (1945-50-55- for 1955, 1950-55-60 for 1960, 1955-60-65 for 1965); UNESCO, Statistical Yearbook, various issues.

Technical Education: Number of graduates from the third level of education who majored in agriculture per ten thousand male workers in agriculture, averages of five years ending 1955, 1960 and 1965 respectively; UNESCO, *Statistical Yearbook*, various issues.