THE PRODUCTION STRUCTURE OF WORLD AGRICULTURE: AN INTERCOUNTRY CROSS-SECTION ANALYSIS

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THE international comparison of agricultural production and productivities pioneered by Colin Clark [2] was advanced by Hayami and associates [5] [7] [9] [10], who attempted a comprehensive analysis of cross-section comparison of labor and land productivities in agriculture among countries for 1960. It was found that extremely large differences in the agricultural productivities existed between developed and less developed countries.

Since then, major changes have occurred in world agriculture. In advanced industrial economies, the increase in labor productivity in agriculture has been extremely rapid due mainly to dramatic progress in mechanical technology induced by sharp decrease in the agricultural labor force during the two decades of economic boom prior to the "oil crisis," while land productivity has also been increased persistently by the systematic application of biological sciences to the agricultural production process. In developing countries, the "green revolution" —the diffusion of modern semi-dwarf varieties of rice, wheat, and other cereal crops with high fertilizer-absorbing and high-yielding capacity—has developed since the mid-1960s as if to counteract deterioration in the man-land ratio due to explosive population growth. A major question is whether, with all those developments, the production structure of world agriculture changed during the past two decades and, as the result, agricultural productivity differences between developed and less developed countries were reduced or increased further.

In order to answer this question, we attempt to prepare the intercountry cross-section data of labor and land productivities for 1980 so as to be comparable with the 1960 data. Changes in those partial productivity ratios are compared with changes in the relative endowments of land and labor and, also, with changes in the inputs of fertilizer and farm machinery relative to the land and labor endowments in order to draw inferences on the different types of technological change experienced by the developed and the developing countries. Further, based on the intercountry cross-section data, an aggregate agricultural production function is estimated for 1960, 1970, and 1980 in order to identify possible changes in the production structure of world agriculture.

The basic data are collected from publications by the United Nations organi-

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TABLE

ESTIMATES OF LAND AND LABOR PRODUCTIVITIES, AND TRACTOR HORSEPOWER PER MALE

	Output per Male Worker in WU (Y/L)		Output per Hectare in WU (Y/A)	
	1960	1980	1960	1980
Argentina	34.9	63.8	0.30	0.44
Australia	103.8	256.2	0.09	0.15
Austria	30.5	90.8	2.32	3.49
Bangladesh	2.0	1.8	2.51	3.51
Belgium (& Luxemburg)	47.5	174.7	6.12	10.08
Brazil	9.3	13.2	0.56	0.72
Canada	66.1	193.6	0.58	0.85
Chile	11.4	19.8	0.47	0.48
Colombia	8.3	17.2	0.79	1.37
Denmark	46.4	131.2	4.60	5.58
Egypt	4.4	4.6	6.90	9.18
Finland	30.5	104.2	2.02	3.34
France	32.4	101.8	2.49	4.09
Germany, F. R.	37.1	113.7	4.00	5.99
Greece	9.1	25.8	1.22	2.21
India	2.2	3.1	1.06	1.58
Ireland	20.1	58.7	1.52	2.38
Israel	25.9	101.8	1.84	4.96
Italy	14.5	48.0	3.40	4.97
Japan	10.3	27.8	8.64	12.23
Libya	3.6	12.9	0.05	0.14
Mauritius	10.1	10.6	6.68	7.18
Mexico	5.1	7.5	0.27	0.52
Netherlands	43.1	109.1	7.21	14.11
New Zealand	140.5	235.0	1.21	1.71
Norway	31.0	94.0	3.09	4.18
Pakistan	3.1	4.2	0.90	1.62
Paraguay	4.9	6.5	0.08	0.14
Peru	9.6	10.1	0.26	0.37
Philippines	3.3	5.9	2.11	3.47
Portugal	7.1	18.7	1.70	1.98
South Africa	11.2	16.7	0.16	0.30
Spain	9.2	44.8	1.12	2.15
Sri Lanka	3.6	4.8	2.19	2.98
Surinam	13.7	47.3	4.46	9.63
Sweden	43.0	122.7	2.33	3.20
Switzerland	29.2	77.6	3.38	4.53
Syria	7.2	10.0	0.31	0.65
Taiwan	7.1	12.4	10.34	18.65
Turkey	6.1	12.7	0.59	1.09
United Kingdom	47.0	116.3	1.94	3.09
United States	93.8	285.1	0.80	1.16
Venezuela	7.8	22.7	0.28	0.55
Yugoslavia	6.6	14.3	1.14	2.00

I

LAND-LABOR RATIO, FERTILIZER INPUT PER HECTARE,
WORKER IN AGRICULTURE, 1960 AND 1980

Hectares per Male Worker (*A/L*)		Fertilizer Input per Hectare in Kg (*F/A*)		Tractor Horsepower per Male Worker in Hp. (*M/L*)	
1960	1980	1960	1980	1960	1980
116.0	146.1	0.1	0.5	2.36	7.05
1,153.1	1,764.5	1.3	2.5	19.21	72.47
13.1	26.0	54.5	119.9	7.27	91.69
0.8	0.5	1.8	28.9	0.00	0.01
7.8	17.3	203.0	300.6	5.88	65.34
16.7	18.3	1.3	13.1	0.22	1.18
113.4	228.5	5.2	26.6	30.32	135.90
24.1	40.9	5.5	7.1	0.81	2.01
10.5	12.5	1.8	11.4	0.37	0.63
10.1	23.5	123.4	225.3	10.41	78.16
0.6	0.5	79.4	184.7	0.05	0.18
15.1	31.2	75.8	188.9	12.11	103.23
13.0	24.9	63.1	163.2	7.14	59.52
9.3	19.0	161.8	254.4	10.54	85.02
7.4	11.7	16.2	55.4	0.68	6.95
2.0	2.0	1.9	20.3	0.01	0.15
13.2	24.6	36.9	107.6	3.47	28.92
14.1	20.5	26.4	62.6	2.49	17.92
4.3	9.6	44.3	100.2	1.74	25.48
1.2	2.3	259.8	384.5	1.03	17.70
73.8	94.5	0.3	4.5	0.53	5.57
1.5	1.5	183.7	219.3	0.14	0.18
19.4	14.3	1.8	10.8	0.23	0.70
6.0	7.7	201.6	317.6	4.79	30.29
116.2	137.6	20.0	36.9	21.70	50.46
10.0	22.5	140.4	268.9	15.22	131.25
3.5	2.6	1.1	28.2	0.02	0.33
60.9	48.1	0.1	0.1	0.07	0.38
36.9	27.5	2.6	3.9	0.25	0.51
1.6	1.7	9.3	33.5	0.03	0.13
4.2	9.5	26.4	61.2	0.28	6.32
69.1	55.8	2.1	8.8	1.52	4.41
8.3	20.9	20.0	49.2	0.32	13.66
1.7	1.6	25.5	45.3	0.01	0.57
3.1	4.9	21.7	67.8	1.13	4.75
18.5	38.4	66.8	139.0	20.18	81.40
8.6	17.1	49.1	78.7	2.79	31.50
23.4	15.5	0.6	5.7	0.20	1.18
0.7	0.7	198.6	428.1	0.03	0.33
10.3	11.7	0.8	20.4	0.26	3.90
24.2	37.6	49.5	106.1	15.82	46.80
117.0	246.6	16.4	44.5	41.38	151.81
27.6	41.4	0.7	7.7	0.46	2.89
5.8	7.2	17.0	54.6	0.44	8.13

zations (FAO and ILO), the European Community, the Organization of Economic Co-operation and Development, and the governments of various countries. These data were processed for 1960 by Hayami and associates [10] to be consistent with the definitions of variables and to be comparable among countries. For this study, the data for 1970 and 1980 are also collected and processed to be consistent with the definitions of the 1960 data, while the 1960 data themselves were revised by correcting obvious inconsistencies with more recent statistics. In principle, 1957–62 averages are taken for 1960, 1967–72 averages for 1970, and 1975–80 averages for 1980, for flow variables such as output and fertilizer input, whereas stock variables such as land machinery are measured by 1960, 1970, and 1980 levels. For 1980, averages are taken for 1975–80 instead of 1977–82 because data were available only up to 1980 at the time of this study.

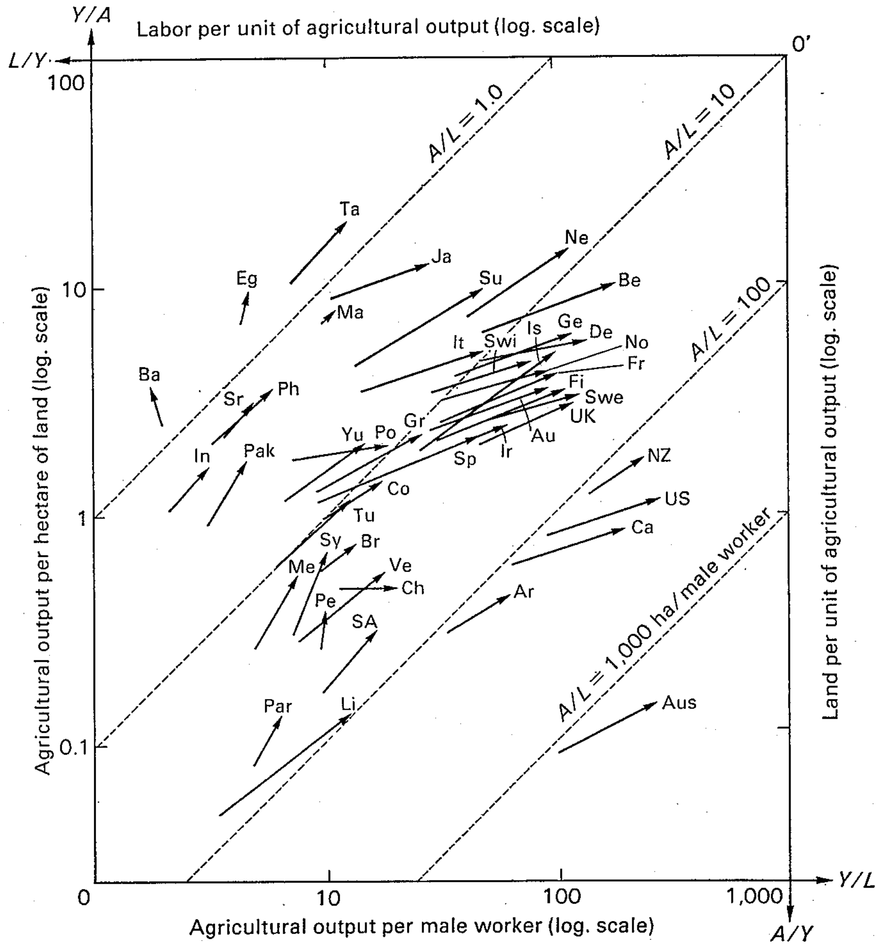
I. COMPARISON IN PARTIAL PRODUCTIVITIES

First, the two partial productivity measures, output per male worker in agriculture and output per hectare of agricultural land, are compared in order to illustrate the wide variations in the relationship between factor endowments and agricultural output among countries and over time. Data of gross agricultural output, net of seeds and feed, in wheat units (one wheat unit [WU] is equivalent to one metric ton of wheat) were prepared for 1960 in Hayami and associates [10]. For 1980, the 1960 data are extrapolated by the FAO indexes of agricultural production for respective countries. Labor and land used for the analysis are, respectively, the economically active male population in agriculture and the area of agricultural land including permanent pasture land.

The labor and land productivities of forty-four countries calculated for 1960 and 1980 are shown in the first two columns of Table I. Differences among countries in these partial productivity ratios are indeed great. In 1960, agricultural output per male worker measured in wheat units ranged from 2.0 (Bangladesh) to 140.5 (New Zealand), and output per hectare ranged from 0.05 (Libya) to 10.34 (Taiwan). By 1980, the ranges widened further—1.8 (Bangladesh) to 285.1 (the United States) for output per worker, and 0.14 (Libya) to 18.65 (Taiwan) for output per hectare.

The labor and land productivity ratios in Table I are plotted in Figure 1 with labor productivity (Y/L) on the horizontal axis and land productivity (Y/A) on the vertical axis, both measured in the logarithmic scale (Y, L, and A represent, respectively, total output, labor, and land in agriculture). For each country, the 1960 position is connected to the 1980 position by an arrow representing a path of output growth for given changes in labor and land in agriculture. Viewed from the top right corner of Figure 1, marked $0'$, each country's position represents a combination of labor and land for producing one unit of agricultural output. Thus, a contour connecting the United States, New Zealand, Belgium, the Netherlands, and Taiwan may be considered an efficiency frontier or an efficient unit isoquant of world agriculture, with respect to the use of labor and land.

Fig. 1. International Comparison of Labor and Land Productivities in Agriculture



Ar:	Argentina	Gr:	Greece	Ph:	Philippines
Aus:	Australia	In:	India	Po:	Portugal
Au:	Austria	Ir:	Ireland	SA:	South Africa
Ba:	Bangladesh	Is:	Israel	Sp:	Spain
Be:	Belgium (& Luxemburg)	It:	Italy	Sr:	Sri Lanka
		Ja:	Japan	Su:	Surinam
Br:	Brazil	Li:	Libya	Swe:	Sweden
Ca:	Canada	Ma:	Mauritius	Swi:	Switzerland
Ch:	Chile	Me:	Mexico	Sy:	Syria
Co:	Colombia	Ne:	Netherlands	Ta:	Taiwan
De:	Denmark	NZ:	New Zealand	Tu:	Turkey
Eg:	Egypt	No:	Norway	UK:	United Kingdom
Fi:	Finland	Pak:	Pakistan	US:	United States
Fr:	France	Par:	Paraguay	Ve:	Venezuela
Ge:	Germany, F.R.	Pe:	Peru	Yu:	Yugoslavia

Note: The 1960 data points are connected to the 1980 points by arrows (data from Table I).

Since both axes of Figure 1 are expressed in the logarithmic scale, each of the forty-five degree lines represents a uni-land/labor ratio line (uni-A/L line) corresponding to a certain land area per male worker. By identity, labor productivity (Y/L) can be partitioned to land-labor ratio (A/L) and land productivity (Y/A):

$$Y/L \equiv (A/L) \times (Y/A)$$

or

$$\log(Y/L) \equiv \log(A/L) + \log(Y/A) .$$

Therefore, arrows parallel to the uni-A/L lines (such as Taiwan and the Philippines) represent countries following a growth path in which an increase in land productivity was the sole contributor to an increase in labor productivity. Arrows with slopes steeper than the uni-A/L lines (such as Egypt and Peru) represent a path in which the increase in labor productivity was smaller than that of land productivity by the amount of decrease in the land-labor ratio, whereas those with less steep slopes (such as the United States and Canada) represent a path in which the increase in labor productivity was enhanced by both the increased land productivity and the increased land-labor ratio.

In every country, both government policies and individual farmers' efforts should have been geared for increasing output and income per worker engaged in agricultural production or to move the country's position in Figure 1 to the right. In general, in advanced industrial economies the rates of growth in total population and labor force were low and those of labor absorption by the nonagricultural sectors were high so that the labor force in agriculture decreased rapidly from 1960 to 1980, resulting in marked improvements in the land-labor ratio. Thus, the high-income countries were able to increase their labor productivities by moving up to higher A/L lines to the right.

On the other hand, partly because of the high population growth rates and partly because of insufficient labor absorption by nonagriculture, most low-income countries experienced during the past two decades an absolute increase in agricultural labor population, resulting in deterioration in the land-labor ratio in agriculture. This trend applied not only to the low-income countries in Asia characterized by high population density but also to those in new continents, such as Mexico and Peru, traditionally endowed with the relatively favorable land-labor ratios. It appears that by the 1960s the strong population pressure in developing countries, even in the new continents, had already reached a point at which the marginal cost of opening new land for cultivation began to rise sharply. In order to counteract the population pressure, serious efforts were made to increase the output per unit of land area by investing in the development of land infrastructure, such as irrigation, and of land-saving technologies. With those efforts to increase land productivity, the low-income countries were able to increase output per worker along the paths parallel to or steeper than the uni-A/L lines. Yet, to the extent that the land-labor ratio was fixed or declined, the rates of growth in labor productivity in the low-income countries were lower than those of the high-income countries.

Such contrasts in agricultural growth patterns between the high-income and

TABLE II

COMPARISON AMONG COUNTRY GROUPS OF AGRICULTURAL OUTPUT PER MALE WORKER (Y/L), AGRICULTURAL OUTPUT PER HECTARE (Y/A), AND LAND-LABOR RATIO (A/L), 1960 (1957–62 AVERAGES) AND 1980 (1975–80 AVERAGES)

	Developed Countries (DC)			Middle-stage Countries (MC)	Less Developed Countries (LDC)
	Average	New Continents	Other		
Labor productivity (Y/L: WU/worker):					
1960	41.0	97.5	31.4	9.9	4.7
	(100)	(238)	(77)	(24)	(12)
1980	116.1	240.1	92.8	23.9	6.4
	(100)	(207)	(80)	(21)	(6)
Land productivity (Y/A: WU/ha):					
1960	2.20	0.48	3.53	0.76	1.04
	(100)	(22)	(160)	(35)	(47)
1980	3.29	0.70	5.30	1.33	1.61
	(100)	(21)	(161)	(40)	(49)
Land-labor ratio (A/L: ha/worker):					
1960	18.6	205.4	8.9	13.1	4.6
	(100)	(1,103)	(48)	(70)	(24)
1980	35.3	342.0	17.5	18.0	4.0
	(100)	(970)	(49)	(51)	(11)
Growth rate, 1960–80 (%/year)					
Y/L	5.9	5.1	6.0	5.0	1.7
Y/A	2.3	2.1	2.3	3.2	2.5
A/L	3.6	2.9	3.8	1.8	−0.8

Note: Geometric means of data in Table I are taken for each country group. Inside of parentheses with the average of developed countries set equal to 100.

DC: New continents—Australia, Canada, New Zealand, United States.
Other—Austria, Belgium, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, Switzerland, United Kingdom.

MC: Argentina, Brazil, Chile, Mexico, Greece, Israel, Ireland, Libya, Portugal, South Africa, Spain, Surinam, Taiwan, Venezuela, Yugoslavia.

LDC: Bangladesh, Colombia, Egypt, India, Mauritius, Pakistan, Paraguay, Peru, the Philippines, Sri Lanka, Syria, Turkey.

the low-income countries are confirmed by a comparison among three groups of countries—seventeen high-income developed countries (DCs) with per capita GNP in 1980 higher than U.S.$6,000 (of which four countries are located in the new continents), fifteen middle-stage countries (MCs) between $1,500 and $6,000, and twelve low-income less-developed countries (LDCs) below $1,500, classified according to the World Bank data [14] (an exception to this classification rule is Libya which is classified as MC despite its per capita GNP of more than $8,000 which is due to a large oil revenue). The comparison in Table II indicates that the wide gap in labor productivity in agriculture between

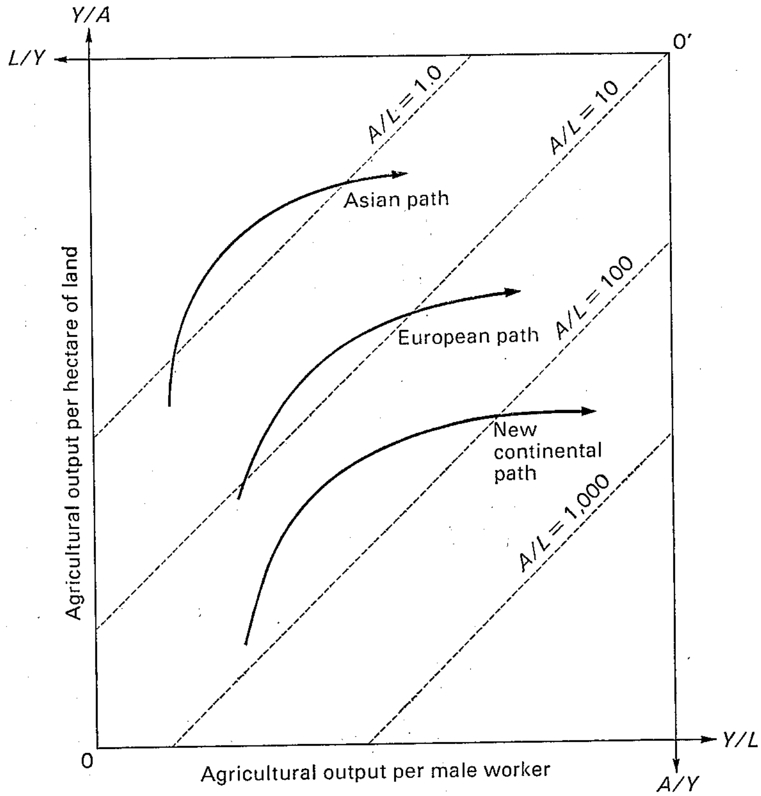
DCs and LDCs widened further; while agricultural output per male worker in LDCs increased from 4.7 WU in 1960 to 6.4 WU in 1980 at a growth rate of 1.7 per cent per year, that of DCs increased from 41.0 to 116.1 WU at a rate as high as 5.9 per cent, so that labor productivity in LDCs as a percentage of that of DCs declined by one-half from 12 per cent in 1960 to only 6 per cent in 1980. Meanwhile, the rate of increase in land productivity in LDCs kept up with that of DCs, and therefore, the widening gap in labor productivity was solely explained by a decline in the land-labor ratio in LDCs both absolutely and relatively. LDC growth performance was also inferior compared with MCs in which the rates of increase in both land productivity and the land-labor ratio kept up with those of DCs.

Although the directions of agricultural productivity growth represented by the arrows in Figure 1 are similar among countries at the same stage of economic development, their positions are different corresponding to different initial factor endowments. Three distinct scatters of the arrows can be observed, each representing a long-term growth path: (a) the path indicated by the group of countries in the new continents, as well as Libya and South Africa, that are scattered around the $A/L=100$ line; (b) the path indicated by countries in Europe and also Israel, Syria, and Turkey, scattered around the $A/L=10$ line; and (c) the path indicated by countries in Asia, as well as Egypt and Mauritius, scattered around the $A/L=1.0$ line. Stylized pattern of these three growth paths are shown in Figure 2.

Each path seems to reflect a long-term process of agricultural growth under alternative man-land ratios. In Asia, land has traditionally been the major factor limiting the increase in output; there the major efforts have long been made in countries like Japan and Taiwan to economize on the use of land or to substitute man-made inputs, e.g., fertilizer, for it. This growth process has been accentuated for the past two decades by further deterioration in the man-land ratio due to the explosive population growth which began in the 1920s and 1930s and accelerated since World War II. The dramatic development of modern semi-dwarf varieties of rice and wheat with high-yielding and high fertilizer-absorbing capacities in the tropics since the late 1960s may be considered an innovation induced by a compelling need to sustain agricultural growth under the condition of declining man-land ratios. An exception among the Asian countries was Japan, which reached the DC stage of economic development characterized by an absolute decrease in agricultural labor force.

In the new continents, a relatively inelastic supply of labor has traditionally represented the most significant constraint on growth of output. In order to ease this constraint, farmers have tried to substitute power and machines for labor in order to expand the area cultivated per worker. Those efforts have enabled DCs in the new continents to achieve superiority in labor productivity in agriculture. However, the high population pressure of the past several decades has compelled new continental LDCs to seek agricultural growth in a direction similar to those in Asia. Such a trend will continue until those countries reach a stage at which the agricultural labor force begins to decline absolutely.

Fig. 2. Stylized Patterns of Growth in Labor and Land Productivity in Agriculture

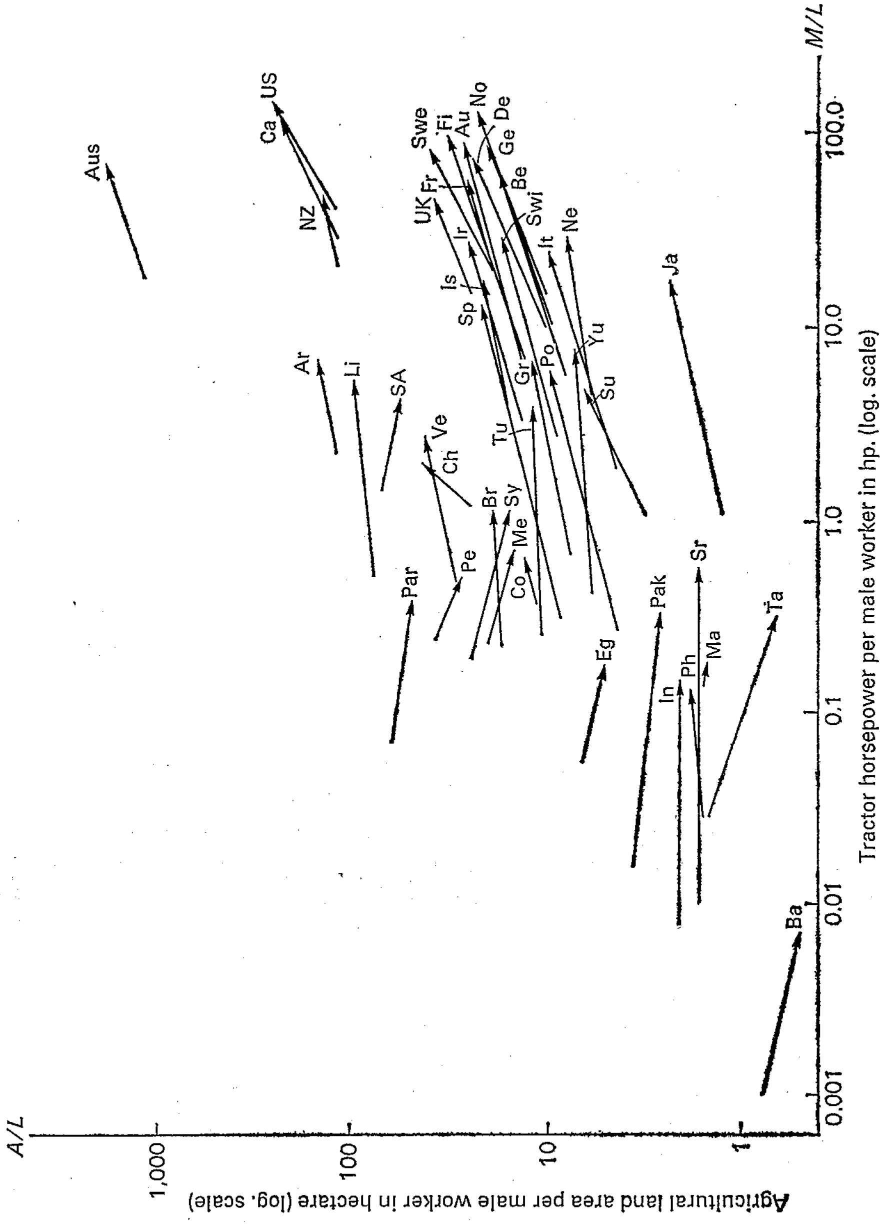


II. PROCESS OF SUBSTITUTION FOR LABOR AND LAND

In the previous section agricultural growth was viewed as a process of substitution of man-made inputs for labor and land. This process may be visualized in Figure 3, which associates the land-labor ratio (A/L) with tractor horsepower per male worker (M/L), and in Figure 4, which associates land productivity (Y/A) with fertilizer input per hectare (F/A). Fertilizer is used here as a proxy or index for the factors which substitute for land, and tractor horsepower is used as a proxy for the factors which substitute for labor. The positive association between A/L and M/L in Figure 3 seems to indicate a process by which the constraint on agricultural production imposed by the endowment of labor was mitigated by increased investments in power and machinery per worker so that the average land area cultivated by one worker was enlarged. Similarly, the correlation between Y/A and F/A indicates a process of easing the limitation set by land through larger applications of fertilizer per unit of land.

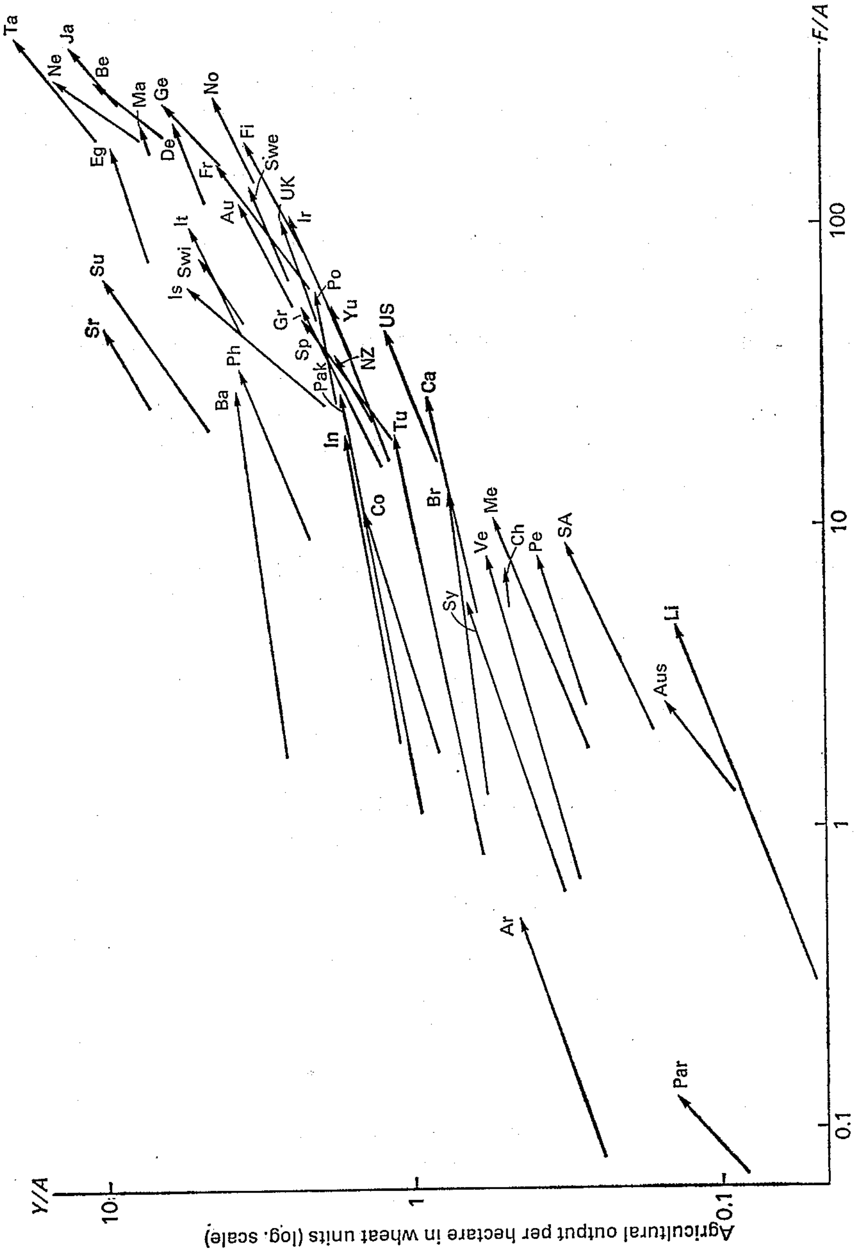
Even though the land-labor ratio is, on the whole, positively associated with tractor horsepower per worker in Figure 3, their correlation is disturbed by dispersion by region—countries in the new continents tend to be located above

Fig. 3. International Comparison of Land-Labor Ratio and Tractor Horsepower per Male Worker



Note: The 1960 data points are connected to the 1980 points by arrows (data from Table I).

Fig. 4. International Comparison of Land Productivity and Fertilizer Input per Hectare



Note: The 1960 data points are connected to the 1980 points by arrows (data from Table I).

a common regression line whereas those in Asia tend to be located below. The opposite relation holds in Figure 4 where new continental countries tend to lie below and Asian countries to lie above. Such relationships seem to reflect differences in land use among the country groups; the new continental countries characterized by sparse population have traditionally used a large percentage of their land as permanent pasture for grazing animals, whereas the percentage of arable land has been larger in the countries of old settlement. In general, the requirement for power and machinery is smaller per hectare of land where a larger percentage of its land is used for permanent pasture, and average output per hectare is also smaller.

In order to confirm our hypothesis on the relations between the land-labor ratio (A/L) and tractor horsepower per worker (M/L), and between land productivity (Y/A) and fertilizer input per hectare (F/A), the following regressions are estimated by applying the ordinary least squares to the intercountry cross-section data:

$$\log(A/L) = 1.421 + \underset{(0.036)}{0.350} \log(M/L) - \underset{(0.110)}{1.209} \log(C/A) - \underset{(0.188)}{0.321} D,$$

$$\bar{R}^2 = 0.747$$

and

$$\log(Y/A) = -0.598 + \underset{(0.037)}{0.473} \log(F/A) + \underset{(0.092)}{0.389} \log(C/A) - \underset{(0.127)}{0.111} D,$$

$$\bar{R}^2 = 0.814,$$

where C/A represents the ratio of arable land area to total agricultural land area including permanent pasture land; D represents a time dummy (0 for 1960 and 1 for 1980); $\bar{R}^2$ is the coefficient of determination adjusted for the degree of freedom; and standard errors of estimated coefficients are shown in parentheses. The coefficients of M/L and F/A are positive and highly significant, and the coefficients of C/A are negative for the A/L equation and positive for the Y/A equation, both highly significant. The coefficients of determination indicate decent fit of the regressions to the data.

These results show that major portions of the variations among countries in the land-labor ratio and land productivity in agriculture are explained by variations in the inputs of labor-substitutes represented by tractor and of land-substitutes represented by fertilizer, respectively, after adjusting for differences in the use of land as represented by differences in the arable land ratio; these relations seem to have remained essentially the same during the past two decades, judging from the results that the coefficients of the time dummy variable are not different from zero at conventional levels of significance.

III. ESTIMATION OF THE AGGREGATE AGRICULTURAL PRODUCTION FUNCTION

In the previous sections we have tried to identify the production structure of world agriculture from the comparisons among countries of partial productivity ratios and input combinations. In this section we attempt to identify the production structure more comprehensively by estimating an aggregate agricultural production function based on the intercountry cross-section data.

The production function employed is of the Cobb-Douglas type, selected mainly for its ease in manipulation and interpretation. The production function includes agricultural output (Y) as a dependent variable, and labor (L), land (A), livestock (S), fertilizer (F), and machinery (M) as dependent variables. While F and M represent modern inputs supplied from the industrial sector, S represents internally accumulated capital within the agricultural sector. National aggregates of output and inputs are deflated by the number of farms in each country so that the production functions are expressed in per farm terms, in order to make inference about scale economies.

In addition to the five input variables, the production function includes a LDC dummy variable which is 0 for DCs and 1 for LDCs in order to adjust for possible difference in technology between DCs and LDCs. The production function is also estimated separately for DCs and LDCs. In order to increase data ranges within each of the DC and the LDC subsamples as well as to increase the size of subsample, the countries classified as MCs in Table II are divided into two groups—one with average GNP per capita in 1980 above U.S.$4,000 and the other below U.S.$4,000. The countries belonging to the higher income group (Greece, Ireland, Israel, and Spain) are included in the DC subsample and those in the lower income group (Argentina, Brazil, Chile, Libya, Mexico, Portugal, South Africa, Taiwan, Venezuela, and Yugoslavia) are included in the LDC subsample. Surinam is excluded from the production function analysis because the data on the number of farms is not available. Thus, the DC subsample comprises twenty-one countries and the LDC subsample comprises twenty-two countries.

A major problem in estimating the production function including as many as five independent variables is multicollinearity. The intercorrelation is especially serious between land and livestock, which made insignificant or even negative the coefficients of land estimated by the ordinary least squares (OLS). In order to avoid the multicollinearity problem, we have tried the Kendall [11] principal-components regressions (PCR) in addition to OLS. In applying PCR, a rule was set so that the principal components having smaller characteristic roots are deleted up to the point at which 95 per cent of the total system variations can be explained by the remaining components.

Results of estimation of the Cobb-Douglas production function are summarized in Table III; each column shows the results of a regression including estimates of production elasticities and their standard errors (in parentheses), the standard error of estimates and the coefficient of determination adjusted for the degree of freedom ($\bar{R}^2$).

Considering the crudeness of data, the levels of statistical significance of regression coefficients seem satisfactory in most cases, except the OLS estimates of the coefficient of land. The application of PCR improves the estimates of the coefficient of land, as compared with the OLS estimates; it increases the

TABLE III

ESTIMATES OF THE INTERCOUNTRY AGRICULTURAL PRODUCTION FUNCTION, BASED ON THE SAMPLE OF FORTY-THREE COUNTRIES, 1960, 1970, AND 1980

Period & category	All Countries						1960–70–80 Pooled					
	1960		1970		1980		All Countries		LDC		DC	
Estimation method	OLS	PCR	OLS	PCR	OLS	PCR	OLS	PCR	OLS	PCR	OLS	PCR
Regression number	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Coefficients of:												
Labor (L)	0.424	0.504	0.350	0.461	0.369	0.406	0.354	0.407	0.377	0.459	0.640	0.613
	(0.146)	(0.119)	(0.126)	(0.085)	(0.115)	(0.082)	(0.072)	(0.049)	(0.121)	(0.076)	(0.088)	(0.075)
Land (A)	−0.008	0.081	0.031	0.061	0.026	0.077	0.017	0.089	−0.095	0.094	0.093	0.083
	(0.075)	(0.026)	(0.068)	(0.025)	(0.071)	(0.027)	(0.040)	(0.013)	(0.078)	(0.015)	(0.034)	(0.024)
Livestock (S)	0.317	0.186	0.278	0.176	0.331	0.256	0.331	0.190	0.360	0.134	0.145	0.188
	(0.097)	(0.032)	(0.088)	(0.019)	(0.099)	(0.043)	(0.054)	(0.012)	(0.105)	(0.026)	(0.073)	(0.011)
Fertilizer (F)	0.201	0.188	0.336	0.262	0.224	0.224	0.242	0.230	0.193	0.205	0.271	0.261
	(0.066)	(0.032)	(0.087)	(0.023)	(0.079)	(0.038)	(0.042)	(0.013)	(0.067)	(0.028)	(0.084)	(0.024)
Machinery (M)	0.119	0.113	0.069	0.135	0.121	0.111	0.098	0.129	0.178	0.112	0.190	0.168
	(0.066)	(0.020)	(0.077)	(0.006)	(0.074)	(0.024)	(0.040)	(0.004)	(0.064)	(0.018)	(0.060)	(0.010)
LDC dummy	−0.290	−0.451	−0.326	−0.421	−0.596	−0.703	−0.419	−0.438				
	(0.218)	(0.190)	(0.228)	(0.043)	(0.224)	(0.184)	(0.127)	(0.040)				
Time dummy: 1970							0.015	0.007	−0.135	−0.049	0.098	0.119
							(0.079)	(0.067)	(0.128)	(0.123)	(0.075)	(0.068)
1980							0.053	0.051	−0.231	−0.071	0.232	0.259
							(0.090)	(0.064)	(0.146)	(0.132)	(0.088)	(0.078)
Coeff. of det. ($\bar{R}^2$)	0.905	0.877	0.926	0.921	0.934	0.932	0.925	0.920	0.867	0.852	0.955	0.954
S.E. of estimates	0.346	0.357	0.325	0.336	0.335	0.338	0.335	0.346	0.389	0.410	0.204	0.205
Sum of input coefficients	1.052	1.071	1.064	1.096	1.071	1.074	1.042	1.044	1.014	1.005	1.340	1.312
	(0.110)	(0.108)	(0.093)	(0.087)	(0.084)	(0.077)	(0.053)	(0.053)	(0.071)	(0.049)	(0.080)	(0.068)

Note: Equations linear in logarithms are estimated by the ordinary least squares (OLS) and the principal component regression (PCR). The standard errors coefficients are in parentheses.

TABLE IV

COVARIANCE-ANALYSIS TESTS OF STABILITY IN PRODUCTION ELASTICITIES OVER TIME AND AMONG COUNTRIES

Stability over 1960, 1970, and 1980:	
F-statistics calculated from	
Q1, Q3, Q5, and Q7	0.98
Q2, Q4, Q6, and Q8	1.11
Theoretical *F*-values with 12 and 108 degrees of freedom	
5 per cent level of significance	1.85
1 per cent level of significance	2.36
Stability between DC and LDC:	
F-statistics calculated from	
Q7, Q9, and Q11	3.53
Q8, Q10, and Q12	3.05
Theoretical *F*-values with 7 and 113 degrees of freedom	
5 per cent level of significance	2.09
1 per cent level of significance	2.80

magnitudes of the coefficient of land at the expense of the coefficient of livestock, reflecting the high intercorrelation between land and livestock. The PCR estimates are surprisingly good in terms of both our a priori knowledge of relative magnitudes of production elasticities among factors and the magnitudes of estimated coefficients relative to their standard errors, even though the PCR estimates involve some bias and, hence, the standard *t*- (and *F*-) tests are not exactly applicable. On the whole, the estimates of production elasticities are consistent with those in the previous studies [1] [3] [6] [8] [12] [13] [15].

Coefficients of the LDC dummy variable in regressions Q1 to Q8 are negative and significant, especially in the PCR estimates, implying that the production efficiency of LDC agriculture was lower than that of DC agriculture; this implies that the distances of LDCs from the efficiency frontier with respect to the use of land and labor, as observed in Figure 1, are explained not only by lower levels of conventional inputs such as fertilizer, machinery, and livestock but also by lower levels of production efficiency or technology.

The estimates of each production elasticity are similar for 1960, 1970, and 1980. In fact, the *F*-statistics calculated in Table IV show that there was no significant change in production elasticities over time. On the other hand, judging from the *F*-statistics, there were significant differences in the production function between DCs and LDCs. A major difference is that production elasticities are uniformly larger for DCs than for LDCs with the result that the sum of the coefficients of inputs for DCs is significantly larger than 1, whereas the sum is not significantly different from 1 for LDCs. Such results show that, while LDC agriculture was characterized by constant returns to scale, DC agriculture was subject to increasing returns; this difference seems to be a major factor underlying the negative coefficients of LDC dummy in regressions Q1 to Q8 based on the DC-LDC combined sample.

Such results are consistent with our knowledge on the basic difference in agricultural technology between DC and LDC. For the past two decades, the agricultural labor force in DCs declined at very rapid rates; the decrease in labor force was associated with dramatic progress in mechanical technology and acceleration of fixed capital investments in large machineries. The scale economies usually stem from the lumpiness or indivisibility of fixed capital. It is quite reasonable to expect that agricultural technology in DCs which was geared for facilitating substitution of labor by lumpy farm machineries, was characterized by scale economies. In fact, our estimates of the DC production function are consistent with the results of Griliches' study [4] of aggregate agricultural production function for the United States; the sum of the coefficients of the conventional inputs in his estimation was about 1.3, which is exactly the same as ours, while his estimates of individual coefficients were also similar to ours.

Contrary to DCs, LDCs experienced absolute increases in agricultural labor force, and, as the result of strong population pressure, the land-labor ratio declined as observed before. In such a situation, the major effort of technological development was directed to save land by applying more labor- and land-substituting inputs, such as fertilizer, per hectare of farmland. A major achievement of this effort was the development of modern fertilizer-responsive, high-yielding varieties of rice and wheat in the tropics, heralded as the "green revolution." It is reasonable to expect that the land-saving oriented technology in LDCs was scale-neutral, since seeds, fertilizer and chemicals are divisible and can be applied at any scale. Even though several areas in LDCs experienced significant progress in farm mechanization, such as installation of power pumps for irrigation and substitution of tractors for draft animals, the scale neutrality estimated in our LDC production function seems to indicate that in LDCs the development of scale-neutral land-saving technology was far more dominant relative to that of labor-saving mechanical technology.

It is interesting to find that the coefficients of time dummies in the estimates of the LDC production function are negative but not statistically significant at conventional levels, implying that there was no technological advancement in LDC agriculture if measured by an upward shift in the production function. On the other hand, the coefficients of time dummies, especially that of 1980, were positive and significant, indicating upward shifts in the DC production function.

It is rather surprising to find that the LDC production function did not shift upward from 1960 to 1980 in spite of the development and diffusion of green-revolution technologies. To explain this anomaly, it is necessary to understand that the production function estimated on the intercountry cross-section data is not a production function in the sense of neoclassical economics but a metaproduction function of the Hayami-Ruttan sense: that is, an envelope of neoclassical production functions, each corresponding to a specific technology actually being used in each country [9]. In terms of this concept the development and diffusion of high-yielding and high fertilizer-responsive varieties of rice and wheat, for example, may be considered a shift along the metaproduction function corresponding to a decline in the land-labor ratio in LDC agriculture. Technological change in DC agriculture involved a similar shift but to the opposite direction corresponding to an increase in the land-labor ratio. In addition, the rich endowment of scientific research and development capacity in DCs would have enabled an upward shift in the portion of metaproduction surface which each DC was facing. Thus, the difference in the scientific research and development capability seems to be a major factor, besides the difference in relative resource endowments, underlying differences in both the levels and the rates of change in labor productivity in agriculture between DCs and LDCs.

IV. CONCLUSION

In this paper we attempted to identify the production structure in world agriculture and any changes which have occurred during the past two decades through an international comparative analysis. First, labor and land productivities were compared among forty-four countries in 1960 and 1980. It was found that the difference in labor productivity between developed and less developed countries was not only extremely large but also widened further from 1960 to 1980. Meanwhile, the rate of growth in land productivity in LDCs kept up with that of DCs. A major factor underlying the widening gap in labor productivity was identified as changes in the land-labor ratio in opposite directions between DCs and LDCs; the land-labor ratio increased in DCs due to rapid labor absorption in the nonagricultural sectors and it decreased in LDCs because of explosive population growth and insufficient labor absorption in nonagriculture.

Stable relations were maintained among countries of increasing land area cultivated per worker by substituting power and machinery for labor and of increasing yields per hectare by substituting fertilizer for land. DCs were able to increase their labor productivity very rapidly by exploiting the opportunity opened by absolute reduction in the agricultural labor force through development of labor-saving technologies in order to facilitate substitution of power and machinery for labor. This route of development being closed because of the strong population pressure, LDCs had to rely on the development of land-saving technologies to facilitate substitution of land by fertilizer and other forms of land-substitutes.

Estimation of the aggregate agricultural production function based on the intercountry cross-section data shows that the production structure of world agriculture in terms of production elasticities of inputs was stable during the past two decades. However, the level of production efficiency or technology was found to be lower for LDCs than for DCs. Moreover, the difference in efficiency levels seems to have widened over time. Thus, the widening gap in labor productivity in agriculture between DCs and LDCs resulted not only from the increasing difference in land and capital per worker but also from the difference in the rates of growth in production efficiency that stemmed from the difference in the scientific research and development capability to generate a stream of more efficient technologies.

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