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Agricultural Research and Productivity--
An International Analysis

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The present paper surveys several aspects of an intercountry study of agricultural research and its contribution to productivity. The first section presents some recently accumulated data and a preliminary analysis of the agricultural research system. The second section utilizes a production function framework to analyze technological improvements in countries and the contribution of research created knowledge to productivity.

I. Agricultural Research

Data on agricultural research are not published regularly. A summary of our estimates is presented in Table 1. The estimated world totals (excluding mainland China) are close to 60,000 scientist (man-year) employed in agricultural research and an annual expenditure of the order of magnitude of 1.1 billion U.S. dollars. The less developed countries produce approximately 30% of the world's agricultural product (by value) but have only 17.3% of the scientist and 11.4% of the dollar expenditures. Most of the less developed countries purchase the services of the scientific man-power at lower costs than the developed countries--$12,290 and $20,010 per year, respectively.

Expenditures and scientific man-power are inputs into the agricultural research system. The output of the system is the new knowledge created or "borrowed" from other countries or disciplines by the agricultural scientists. This knowledge is the factor of production affecting productivity in agriculture. Knowledge is intangible, as a proxy measure of its creation we took the numbers of scientific publications in the agricultural sciences. More than 200,000 studies published over the period 1948-68 were counted in 8 crops (wheat, barley, etc.), 3 livestock categories, phytopathology, soil sciences and plant physiology. The last is a measure of general biologic work conducted mainly outside the agricultural research system. Publications were counted from abstracting journals and assigned to countries by the address of the first author. Only genuine scientific contributions are abstracted (instruction pamphlets, for example, are not). This secures a floor to the quality of the counted publications.

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Table 1 : Agricultural Research - Summary of Basic Data

	Developed Countries	Developing Countries	World
Manpower and Expenditures (annual data for 1965)			
Scientists (scientific man year)	49,262	10,292	59,560
Total expenditures (million US$)	985.7	126.6	1,112.3
Ratio to value of product	.871	.259	.688
Expenditure per farm (US$)	17.25	1.07	3.21
Expenditure per scients (US$)	20,010	12,290	18,675
Publications (Averages 1962-68)			
Plant physiology	27,074	2,828	29,902
Crops	32,115	7,232	39,347
Livestock	31,579	2,478	34,057
Total Agriculture	63,694	9,710	73,404
Research expenditures per publication (US$)	108,300	91,300	106,051
Scientific man year per publication	5.41	7.42	5.68

Source:

Evenson, Robert E. and Yoav Kislev, "Investment in Agricultural Research and Extension: A Survey of International Data," Economic Growth Center, Yale University, Discussion Paper No. 124 (mimeo).

Of course, the information contents of scientific publications varies much from one article or book to another and much of the information conveyed is not directly applicable to agriculture. But there is no better measure of research output and the seemingly straightforward measures of inputs--dollars expenditures and man-years--embody wide variations in accounting procedures and in the quality of the scientific manpower employed.

The second part of Table 1 summarizes publication data for the period 1962-68. We do not know what is the share of total publications in the agricultural sciences that was covered by our counts. The calculations of expenditures and manpower input per publication should, therefore, be used only for inter-group comparisons. It is interesting to note the differences between the developed and the developing countries here. The less developed countries spend close to 40% more scientific manpower input per publication, and though their budgets per scientist is lower than in the developed countries, the cost per publication is only 15% smaller than in the developed countries.

At this stage of the analysis two quastions were raised regarding the agricultural research system as an economic entity: (a) what is the "production function" of knowledge? and (b) what are the major factors affecting the allocation of research efforts? Regression results that shed light on these issues are presented in Table 2. The estimated equations are:

(1) $P_j = f(S_j, E_j, p_{14j}, g_j, N_j)$

and

(2) $p_{ij} = f(q_{ij}, Ex_{ij}, g_j, H_j, w_j, p_{14j})e^{\beta_i}$

where

p_{ij} publications in crop or sector i in country j

$P_j = \sum_{i=1}^{13} p_{ij}$ total number of publications in agricultural sciences (not including plant physiology)

S_j scientific man-year in agricultural research

E_j expenditure on agricultural research

Table 2 : Structural Analysis of the Agricultural Research System

A. Production function Equation (1)			B. Allocation of Research Efforts, Equation (2)		
	1	2		3	4
R^2	.840	.907	R^2	.367	.466
Constant	1.183	1.195	Constant	-1.545	-1.469
Scientific Man year (S)	.372 (3.11)	.378 (3.55)	Product (q)	.461 (6.94)	.404 (6.22)
Plant Physiology (p_{14})	.426 (5.67)	.565 (6.98)	Exports (Ex)	.165 (4.50)	.210 (5.68)
GNP/cap . (G)		.212 (1.00)	GNP/cap. (G)	-.204 (.93)	-.208 (1.48)
Newspaper/cap. (N)		-.214 (1.24)	Share of Agr. in GNP (H)	-.072 (.24)	
			Plant Physiology (p_{14})	.304 (6.45)	.313 (7.13)
			Dummies (β)		yes

Notes:

Date are averages for 1962

In parenthesis: t values

No. of observation:

Part A : 44

Part B : 435

G_j GNP per capita

N_j number of newspapers per 10,000 people

q_{ij} value of product i (i = 1, ..., 11) in country j

Ex_{ij} share of export in value of product i

H_j share of farm labor in total labor force

w_j number of agricultural workers (males).

and f( ) is of the Cobb-Douglas type.

In (2) β_j is a "product effect"--a dummy variable measuring ease of publication or biases in counting in product i. Soil sciences and phytopathology were not included in this analysis. The elasticity of knowledge (publication) production with respect to number of scientists is of the order of .4 (Table 2 Regressions (1), (2)). Plant physiology work affects research productivity positively and significantly. With this variable in the regression the two variables (G, N) which may be taken as measures of the quality (productivity) of the research system are not significant. High income countries spend more on science, biological science included, regression (2) indicates that it is not low income that affect productivity, in applied agricultural research, but the poverty or absence of general biological scientific work.

As the regressions in Part B of Table 2 indicate, larger product values entail more publications in the respective areas, but the elasticity is only of the order of magnitude of .4 . The positive coefficient of the export variable indicates that countries direct comparatively more research to export crops. In some instances, this is the result of the structure of the research institutions inherited from the colonial times. Perhaps one would not expect the negative signs of the coefficients of G and H in regression (3), but the very low t values indicate the unimportance of these parameters given the other variables in the equation.

II. Agricultural Productivity

The basic input-output data set is the one used by Hayami and Ruttan.* Their's covered 44 countries for the period 1955, 1960, 1965. This set was extended by adding 1968 and a research variable. Availability of research data limited our set to 36 countries.

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* Hayami, Yujiro and Vernon W. Ruttan, (1971) Agricultural Development: An International Perspective. (John Hopkins Press, Baltimore and London)

The research variable used was the stock of knowledge in a country, defined as

$$(3) \quad K(t) = \sum_{s=1948}^{t} p(s)$$

Thus the stock variable in 1955 was the sum of the publications over the period 1948-1955. One would like to include depreciation, obsolescence and lags in adoption effects in the formulation in (3) but the magnitudes of such effects are not known. (In experiments in another part of our study the analysis could not be improved by incorporating depreciation or lags components.)

The general form of the production function estimated was

$$(4) \quad y = f(X)e^{\alpha_j + \gamma_j t}$$

where f( ) is a Cobb-Douglas function and X is a vector of inputs

x_1 = land

x_2 = labor

x_3 = livestock

x_4 = fertilizers

x_5 = machinery

x_6 = technical education (number of college graduates in agricultural sciences per 10,000 in the farm labor force)

x_7 = research (the variable K)

α_j = a country specific intercept (country "dummy")

γ_j = a country specific time trend coefficient (estimated by creating country specific trend variables assuming the values 1, 5, 10, 13 for the years 1955, 1960, 1965 and 1968, respectively, for the country and zeros elsewhere) .

The inclusion of the last two terms permitted the estimation of countries' relative productivity levels and specific technological improvement coefficients. Estimates are presented in Table 3.

Table 3 : Agricultural Production Function--
Four Period Regressions

Regression	1	2	3	4
R^2	.944	.995	.982	.999
Constant	2.367	2.147	2.207	2.097
1. Land	.045 (1.35)	.142 (3.51)	.068 (1.60)	.151 (5.56)
2. Labor	.237 (6.33)	.032 (1.41)	.167 (3.83)	-.012 (.93)
3. Livestock	.296 (6.39)	.351 (6.80)	.359 (6.19)	.422 (10.85)
4. Fertilizers	.096 (2.90)	.090 (4.01)	.124 (3.78)	.082 (4.70)
5. Machinery	.099 (3.90)	.058 (3.57)	.049 (1.66)	.018 (1.41)
6. Tech . Ed.	.042 (1.92)	.004 (.38)	.084 (3.00)	-.009 (1.09)
7. Research	.144 (4.89)	.066 (3.03)	.101 (3.06)	.046 (2.58)
Country Specific: Dummies (intercepts)	-	yes	-	yes
Trend	-	-	yes	yes
Σ	.773	.673	.767	.661

Notes: Variables 1-5 and output are averages per farm.

No. of observations: 144.

Σ: of coefficientsof variables 1 - 5.

In parenthesis: t values.

Space does not permit a detailed analysis of the results. We will remark on two aspects: (a) the contribution of research, and (b) intercountry productivity differences.

The marginal productivity of investment in research is calculated as follows:

(a) The ratio of research expenditures to agricultural production is taken as 80c per $100 (see Table 1);

(b) The elasticity of publication with respect to man-power or expenditures is taken as .4 (see Table 2);

(c) Elasticity of production with respect to scientific publication is taken as .04 (regression 4, Table 3).

An additional 8c spent on research for every $100 value of agricultural production will amount to additional 10% of research expenditures. This will increase research output (publications) by .04 x .04 = .0016, or 16c for every $100. The marginal benefit-cost ratio for research outlays is therefore 16/8 = 2.0 . The productivity coefficient utilized in calculating research's contribution is the lowest reported and the cost-benefit ratio calculated can, therefore, be taken as a lower bound [since research contributes to technical advance, its coefficient in regressions (3), (4) are likely to be underestimated, due to the inclusion of the trend variable].

The introduction of the country-specific dummy and trend coefficients contributed significantly to the explanation in the regressions in Table 3. These estimates are reported in Table 4. The table should be read as follows. From an identical bundle of inputs, for example, the Netherlands' output will be 210% that of Germany (chosen as a bench mark, the dummy set to 1.00). Technological change in the Netherlands proceeded, over the period 1955-1968, at the pace of .6% per annum, and by this trend parameter the Netherlands' rank is 25.

The country intercept reflects not only genuine differences in efficiency of production and utilization of resources but also systematic errors in the measurement of inputs and output. This factor may explain the very high coefficient for the Netherlands or the comparatively low ranking (32) of Norway. But, in general, the findings of Table 4 are reasonable. The differences in productivity revealed in the table are huge. From the same bundle of inputs, India, for example, will get only 38% of Germany's output and 29% of the output achieved by Japan.

Table 4 : Country-Specific Intercept and Time Trend (Regression 4 of Table 4)

	Intercept (percent of W. Germany)	Trend (percent per annum)	Rank		Intercept (percent of W. Germany)	Trend (percent per annum)	Rank
1. Netherland	210	.6	(25)	19. Portugal°	74	.2	(30)
2. Japan°	133	1.0	(18)	20. Chile°	71	.3	(27)
3. Denmark	128	.9	(21)	21. New Zealand	71	1.2	(15)
4. Taiwan°	127	3.1	(4)	22. Philippines°	69	.4	(26)
5. Belgium	126	1.0	(20)	23. Australia	64	1.8	(6)
6. France	116	1.6	(12)	24. Ireland	61	0	(31)
7. U.S.	115	.3	(28)	25. Finland	60	2.0	(10)
8. Sweden	115	.6	(24)	26. Greece°	60	3.1	(3)
9. Canada	111	1.0	(19)	27. Turkey°	59	1.1	(17)
10. Switzerland	110	.7	(23)	28. South Africa	59	2.7	(5)
11. Israel	109	5.1	(1)	29. Pakistan°	56	-1.2	(35)
12. Argentina°	105	0	(32)	30. Brazil°	55	.9	(22)
13. Italy	102	1.2	(16)	31. Colombia°	55	0	(33)
14. U.K.	102	1.9	(8)	32. Norway	56	.2	(29)
15. West Germany	100	1.4	(13)	33. India°	38	-.5	(34)
16. Austria	81	2.0	(7)	34. Mexico°	37	-2.3	(36)
17. U.A.R.°	81	1.8	(9)	35. Peru°	37	1.6	(11)
18. Spain°	79	1.4	(14)	36. Venezuela	37	3.3	(2)

Notes:

For interpretation, see text.

o : 1961 GNP per capita less than $400.

Table 5 : Average Value of Country Specific Intercept and Time Trend

	Intercept (Percent of W. Germany)	Time Trend (Percent Per Annum)
1. First group of 20 countries in Table 4	101	1.3
Last 16 countries	53	0.9
2. 20 Rich Countries	94	1.5
16 Poor Countries	65	0.7

Note:

Poor countries: with GNP per capita in 1961 less than $400.
(marked o in Table 4).

The question arises whether the gap in productivity is closing over time. Two comparisons are presented in Table 5. In the first, the group of 20 highest countries in Table 4 is compared to the group of 16 lowest. The average intercepts are 101 and 53 forthe first and second groups, respectively. The average time trends of technology are 1.3% for the higher group and 0.9% for the lowest. The gap between these two groups will thus increase over time. The same conclusion is reached comparing the 20 "rich" countries (with 1961 per-capita GNP in excess of $400) with the 16 poor countries of the sample. In 10 years, if the rich start at 94 and proceed at 1.5% per-annum and the poor start at 65 and proceed at .7% per-annum, the rich will be at 109 and the poor at 70. The rich will start from a position in which their productivity level is 1.45 (=94/65) times of that of the poor countries, and their productivity level after 10 years will be 1.55 timesbetter than that of the poor countries. The moral of this finding is that if the poor and low efficiency countries are to close the productivity gap, they have to institute technology and efficiency advancing policies--research, for example.

Summary

Man-power, expenditure and publication data on agricultural research were collected and analyzed. Counts of publications were used as proxies for research created knowledge. A lower bound for the marginal benefit cost ratio for investment in agricultural research is estimated as 2.0. In the period 1955-1968 the rich countries average productivity level was 1.45 that of the poor. The gap between the two groups is widening as technological improvement rate is 1.5% per-annum for the rich countries and only 0.7% for the poor.