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Investment in Agricultural Research and Extension: A Survey of International Data

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The treatment of research and extension activities in an economic framework is of relatively recent origin. It is a measure of the limited emphasis on the economic aspects of these activities that a comprehensive compilation of international data has not heretofore been made. In this paper we report such a compilation. It is the product of an extensive review of existing data sources and of responses to a survey questionnaire sent to research organizations throughout the world. In the following section, data on research and extension expenditures, on numbers of scientists and extension workers, and on scientific publications are summarized by regions of the world.[1] A short section surveys the new international centers. Comparative aspects of the data are explored in the last section in an attempt to identify factors accounting for differential "productivity" of scientists and to investigate the determinants of investment in research.

Summary of International Data

The Appendix presents country data on research and extension. The discussion in the text will be in terms of interregional comparisons; particular attention will be given to the differences between the developed and the less developed countries.

Regional summaries of research and extension personnel and budget data for 1965 are presented in table 1. These data were compiled from a large number of sources,[2] including FAO and OECD regional surveys, as well as published experiment-station budgets and responses to survey questionnaires. Scientists are people doing independent research work, not technicians and assistants. Expenditures have been converted to U.S. dollars at the official exchange rate. Only research and extension activities

[1] More detailed data and a complete list of sources appear in R. E. Evenson and Y. Kislev, "Investment in Agricultural Research and Extension: An International Survey," Economic Growth Center Discussion Paper no. 124, Yale University, 1971.
[2] Ibid.

TABLE 1

AGRICULTURAL RESEARCH AND EXTENSION, 1965 – REGIONAL SUMMARIES

Region*	Expenditures on Research (Million $) (1)	Scientist-Man-Years (2)	Expenditures on Extension (Million $) (3)	No. of Extension Workers (4)
1. North America	390.2	15,283	204.4	9,137
2. Northern Europe	190.0	8,232	106.4	17,480
3. Southern Europe	23.1	2,236	25.1	5,335
4. Oceania, South Africa, Rhodesia	86.7	3,671	(43.0)	(7,950)
5. Eastern Europe and USSR	(233.2)	15,340	(144.0)	(33,400)
6. Latin America	20.6	2,431	22.9	3,883
7. Middle East and North Africa	33.3	1,608	(33.0)	(15,500)
8. South and Southeast Asia	36.0	4,220	(45.9)	28,892
9. East Asia	65.7	5,195	47.4	18,443
10. Sub-Sahara Africa	33.5	1,344	28.0	23,820
Developed countries	985.7	49,262	559.2	87,428
Less developed countries	126.6	10,298	140.9	76,412
World total	1,112.3	59,560	700.1	163,840

NOTE. Numbers in parentheses are based significantly on estimates.
* Developed countries = regions 1–5 plus Japan; less developed countries = regions 6–10 minus Japan.

aimed directly at increasing agricultural productivity are included; food technology and home economics, for example, are not included. All data are by location of work. Thus French or British scientists in Africa are treated as African scientists. All data are for the public-sector activities. Private investment data in research and development are not included.

Several shortcomings and discrepancies should be pointed out. It is inevitable that problems of inconsistency exist in the definitions used by the different sources from which data were collected. In Europe and North America, a scientist usually has graduate training at the Ph.D. level. In the developing countries, this may not be the case, particularly in Latin America, where the basic academic degree of a researcher (Ingenero Agronomo) is a professional degree rather than a research degree. There is perhaps even less consistency in the definition of extension workers: in some countries they are all college graduates, while in others many of them have only high school education or less. Budget data are also not always compatible.

Despite these limiting qualifications, in our judgment the errors are not so gross as to substantially alter the picture presented in the regional summary tables 1–5.

The world total expenditure on research in 1965 (table 1) was $1.1 billion annually, with close to 60,000 scientists engaged in research activity. There were more than 160,000 extension officers with budgets reaching $700 million. As these figures indicate, the production and dissemination of agricultural knowledge is a substantial (and growing) industry, but the economic resources engaged in these activities are much smaller than those devoted to many other public sectors. Table 1 also indicates great differences between the developed and the less developed countries (regions 6–10, excluding Japan) of the world. The LDCs expended 11 and 20 percent of the world research and extension budgets, respectively, and had 17 and 47 percent of the research and extension personnel.

Further comparative regional statistics are presented in table 2. Columns 1 and 2 present ratios of expenditures on research and extension to the value of agricultural production. The two major less developed regions, Latin America and South and Southeast Asia, are ranked lowest by this measure of research expenditure. Conversely, the highest-income regions—North America, northern Europe, and Oceania—rank highest. The picture is somewhat more mixed regarding extension spending, as the LDCs spend more on extension than on research, whereas the developed countries spend 1.8 times as much on research as on extension.

An alternative basis for comparison is expenditures per farm, as calculated in columns 3 and 4 of table 2. The very large differences in size of farm in different regions dominate the results. This particular comparison is not as useful with respect to research as to extension. It is quite plausible that extension efforts should be related to the number of farmers to whom information is to be supplied.

The prices (in U.S. dollars at official exchange rates) of research and extension services vary substantially by regions (cols. 8, 9). The less developed countries as a whole spend roughly 60 percent as much per scientist and only 22 percent as much per extension worker as the developed countries. Some of these differences may be accounted for by the fact that more laboratory equipment and technical assistance per scientist are purchased in the developed countries. It seems, however, that the LDC research systems have higher ratios of technical personnel to scientists than those in the developed countries. Latin America and Southeast Asia have low salaries and low expenditures per scientist. The African countries, on the other hand, have relatively high proportions of expatriate European research workers earning high salaries.

The differences in expenditure per worker between the developed and the developing countries are more pronounced in the extension than in the research systems. To some extent this reflects higher quality differences in the latter systems. Because of the widely varying prices of research and extension services among regions, expenditure data can be somewhat misleading. As an alternative indicator, calculations of the numbers of scientist-man-years and of extension workers per $10 million of agricultural production and numbers of extension workers per thousand farms are presented. The distinction between the developed and less developed countries with respect to research becomes more marked when the comparison is made on this basis. The developed countries engage more than

TABLE 2

AGRICULTURAL RESEARCH AND EXTENSION, 1965—COMPARATIVE STATISTICS

Region	Expenditures as % of Value of Agricultural Production		Expenditures per Farm		Scientist-Man-Years per $10 Million Value of Agricultural Production	Extension Workers		Expenditures per	
	Research (1)	Extension (2)	Research (3)	Extension (4)	(5)	Per $10 Million Agr. Prod. (6)	Per 1,000 Farms (7)	Scientist (8)	Extension Worker (9)
1. North America	1.01	0.53	93.11	48.78	3.97	2.38	2.18	25.53	22.37
2. Northern Europe	0.93	0.53	32.55	16.74	4.03	8.56	2.66	23.08	6.39
3. Southern Europe	0.38	0.41	2.44	2.51	3.68	8.77	0.54	10.33	4.70
4. Oceania, South Africa, Rhodesia	1.61	(0.80)	188.88	(93.68)	6.82	14.75	(17.32)	23.62	(5.41)
5. Eastern Europe and USSR	0.64	(0.39)	7.49	(4.62)	4.09	9.16	(1.07)	15.20	(4.31)
6. Latin America	0.17	0.19	1.57	1.75	2.01	3.22	0.30	8.47	5.89
7. Middle East and North Africa	0.55	(0.55)	4.88	(4.83)	2.68	25.87	(2.27)	20.71	(2.13)
8. South and Southeast Asia	0.24	0.31	0.43	0.55	2.81	19.26	0.35	8.53	(1.59)
9. East Asia	0.79	0.57	7.15	5.16	6.24	22.17	2.01	18.64	2.57
10. Sub-Sahara Africa	0.45	0.38	2.79	2.33	1.81	32.15	1.93	24.93	1.18
Developed countries	0.874	0.496	17.25	9.78	4.37	7.74	1.53	20.01	8.40
Less developed countries	0.259	0.289	1.07	1.19	2.11	15.66	0.64	12.29	1.84

twice as many scientists per dollar's worth of production than do the LDCs, even though scientists' salaries are approximately 60 percent higher in the developed countries.

Expenditures and scientific manpower 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. As a proxy measure of the creation of knowledge, we took the numbers of scientific publications in the agricultural sciences (table 3). More than 200,000 publications were tabulated in the following

TABLE 3

AGRICULTURAL RESEARCH PUBLICATIONS ABSTRACTED IN SELECTED INTERNATIONAL ABSTRACTING JOURNALS, 1948–68

	PUBLICATIONS BY ORIENTATION					ANNUAL PUBLICATIONS PER $100 MILLION* AGRICULTURAL PRODUCTION		
	Plant Physiology (1)	Phyto-pathology and Soil Science (2)	All Crops (3)	All Livestock (4)	Total Agriculture (5)	Crops (6)	Live-stock (7)	Total (8)
North America:								
1948–51 ..	2,130	3,758	6,549	10,000	16,549	7.0	9.8	8.3
1955–61 ..	...	6,854	9,446	10,608	20,053	8.2	8.9	8.3
1962–68 ..	8,831	8,383	12,743	11,265	24,009	9.3	8.2	8.9
Northern Europe:								
1948–54 ..	1,748	1,194	3,458	9,888	13,346	7.2	11.3	13.5
1955–61 ..	...	1,454	4,084	9,958	14,042	7.4	8.9	11.7
1962–68 ..	7,721	2,691	5,491	10,807	16,298	8.6	7.8	11.3
Southern Europe:								
1948–54 ..	245	480	1,026	981	2,007	4.2	6.9	6.1
1955–61 ..	...	365	987	1,016	2,003	3.7	5.2	5.3
1962–68 ..	830	513	1,169	1,387	2,556	4.3	5.1	5.9
Oceania, South Africa, Rhodesia:								
1948–54 ..	172	393	1,254	1,316	2,570	14.1	7.8	10.1
1955–61 ..	...	822	1,350	1,906	3,256	12.1	8.8	10.1
1962–68 ..	1,358	915	1,545	2,291	5,836	10.5	9.5	10.0
Eastern Europe and USSR:								
1948–54 ..	705	213	1,739	1,217	2,956	1.2	1.6	1.6
1955–61 ..	...	1,003	4,283	2,532	6,815	2.3	2.2	2.7
1962–68 ..	6,160	3,144	9,683	5,116	14,799	4.7	3.6	5.1
Latin America:								
1948–54 ..	70	209	858	228	1,086	1.8	1.1	1.6
1955–61 ..	...	291	983	202	1,185	1.6	.9	1.5
1962–68 ..	420	610	1,288	479	1,767	1.8	1.7	1.8
Middle East and North Africa:								
1948–54 ..	33	47	284	202	486	1.0	1.7	1.3
1955–61 ..	...	133	360	303	633	1.2	2.1	1.3
1962–68 ..	690	359	646	405	1,051	1.7	2.4	2.0
South and Southeast Asia:								
1948–54 ..	243	484	1,889	592	2,481	2.7	27.5†	3.5
1955–61 ..	...	792	2,521	745	3,266	2.8	30.2†	3.5
1962–68 ..	1,603	1,594	4,330	1,335	5,664	4.3	46.5†	5.5
East Asia:								
1948–54 ..	110	146	926	322	1,248	2.5	14.7	3.3
1955–61 ..	...	419	1,596	589	2,186	3.4	10.7	4.3
1962–68 ..	2,233	519	1,801	724	2,526	3.4	6.8	4.3
Sub-Sahara Africa:								
1948–54 ..	2	18	274	62	334	1.0	1.2	1.0
1955–61 ..	...	105	419	155	574	1.5	2.8	1.8
1962–68 ..	56	249	651	248	899	1.9	3.9	2.2
Developed countries:								
1948–54 ..	5,044	6,176	14,777	23,724	38,501	4.2	7.9	6.7
1955–61 ..	...	10,902	21,569	26,607	48,176	5.0	6.8	8.6
1962–68 ..	27,074	16,083	32,115	31,529	63,694	6.5	6.6	7.6
Less developed countries:								
1948–54 ..	414†	748	3,480	1,084	4,564	1.9	2.7	2.1
1955–61 ..	...	1,336	4,460	1,407	5,867	2.1	3.1	2.3
1962–68 ..	2,828	2,894	7,232	5,478	9,710	2.8	4.5	3.2

* In 1965 U.S. dollars.
† Data on livestock output are very limited for the region.

areas:[3] (1) wheat, (2) barley, (3) maize, (4) sorghum, (5) rice, (6) sugar crops (cane and beet), (7) potatoes, (8) cotton, (9) animal husbandry (general), (10) poultry, (11) dairy, (12) phytopathology, (13) soil sciences, and (14) plant physiology. The counts were made from abstracting journals, and the publications were classified by countries by the address of the first author. The selection procedures employed by these journals helps to maintain quality of the abstracts. Only genuine scientific contributions are abstracted; instruction pamphlets and similar materials are not counted.

Publication counts can be utilized as a proxy measure of knowledge creation, a measure that has certain advantages as well as limitations. The advantages include the following: (1) It is a "real" measure free of exchange rate difficulties. (2) It is a measure of research accomplishment or output, rather than a measure of inputs. (3) It provides a measure of the commodity orientation of research. (4) The implicit definition of research is contained in the standards applied by the abstracting journals for inclusion. The journals chosen—*Plant Breeding Abstracts* and *Dairy Science Abstracts*, both published by the Commonwealth Agricultural Bureau, and *Biological Abstracts*—have as their stated purpose international coverage of all literature of scientific significance. Thus, our measure includes only a portion of the published literature. (5) Since it is compiled from only three sources, it is less subject to reporting errors and unstandardized definitions.

The chief limitation of the measure is that research "output" is not measured in economic terms. We have elsewhere "tested" the hypothesis that this measure of research activity has economic meaning.[4] Our findings in that study of the productivity of research strongly support the hypothesis that the number of research publications is a good indicator of the economic impact of research activity. This supports the assertion that the screening process utilized by the abstracting journals has been such that the data in table 3 measure "real" scientific activity quite well.

An important advantage of the publications data is that they enable some comparisons over time. Biases toward certain commodities or toward Commonwealth countries, if such biases exist, do not affect the measure of relative changes over time. On this point note that the share of publications from the LDCs rose from 10.6 percent in the 1948–54 period to 13.2 percent in the 1962–68 period. If we exclude Eastern Europe and the USSR from the totals, the LDC share rose from 11.4 percent to 16.6 percent. The extraordinary increase in publications by the Soviet bloc countries is interesting, particularly in view of the rapid increases in food production in Eastern Europe over the last 2 decades.[5]

[3] For further reference the areas of research will be referred to as crops or products (e.g., wheat, barley) or subsector (livestock, poultry).

[4] R. E. Evenson and Y. Kislev, "Research and Productivity in Wheat and Maize," *Journal of Political Economy* 81 (November/December 1973): 1309–1329.

[5] Yoav Kislev, "Innovation and Research in Agricultural Development," in *Proceedings of the Twentieth International Meeting of the Institute of Management Science* (in press).

Table 3 also presents calculations of the ratio of publications to the value of agricultural production in constant 1965 U.S. dollars. Here it is of interest to note that this ratio has remained roughly constant in the developed regions except for Eastern Europe and the USSR, where it has risen markedly. Actually, it has risen somewhat for crop-oriented research and fallen for livestock-oriented research in the developed countries. The LDCs, on the other hand, generally show an increase in this share over time. Latin America once again shows up poorly, with a low and stationary ratio.

Table 4 extends the calculations of table 2 to the publications data. Note here that because of differences in publications per scientist which favor the developed countries, much of the advantage of employing lower-salaried personnel is lost to the LDCs. They end up paying almost as much for a research publication as the developed countries. The African regions pay very high prices per publication because of high salaries and low productivity per scientist. Only South and Southeast Asia (chiefly India and Pakistan) appear to be able to purchase research publications at "bargain" prices.

We present table 5 as an overall summary of our data. Here note that the LDCs have a very low share of general science publications but do much better with respect to agricultural research. Even so, by any relative measure, the data suggest substantial underinvestment in research. The question of optimal investment is not directly addressed in this paper, and we cannot presume to know exactly what an optimal investment program for the LDCs would be. It can, however, be noted that the data in tables 2 and 3 indicate a strong correlation between research investment and economic performance in the agricultural sector. North America, northern

TABLE 4

RESEARCH EXPENDITURES AND SCIENTISTS PER RESEARCH PUBLICATION, 1965

Region	Expenditure per Publication (U.S. $000) (1)	Scientists per Publication (Man-Years) (2)
North America	113.8	4.46
Northern Europe	81.6	3.54
Southern Europe	63.3	6.12
Oceania, South Africa, Rhodesia	158.2	6.69
Eastern Europe and USSR	110.3	7.25
Latin America	81.6	9.63
Middle East and North Africa	221.7	10.71
South and Southeast Asia	44.5	5.21
East Asia	182.1	14.39
Sub-Sahara Africa	260.8	10.46
Developed countries	108.3	5.41
Less developed countries	91.3	7.42

TABLE 5

REGIONAL SHARES, RESEARCH AND EXTENSION EXPENDITURES

Region	Value of Agricultural Production (U.S. Prices) (1)	Agricultural Research: Expenditure (2)	Agricultural Research: Scientists (3)	Research Publications: Agricultural Science (4)	Research Publications: Plant Physiology (5)	Research Publications: General Science* (6)	Agricultural Extension: Expenditure (7)	Agricultural Extension: Staff (8)
North America	.247	.351	.257	.327	.295	.451	.292	.056
Northern Europe	.131	.171	.138	.222	.258	.270	.152	.107
Southern Europe	.039	.021	.038	.035	.028	.024	.036	.033
Oceania, South Africa, Rhodesia	.035	.078	.062	.052	.045	.023	.061	.049
Eastern Europe and USSR	.234	.210	.258	.202	.206	.140	.206	.204
Latin America	.078	.019	.041	.024	.014	.008	.033	.024
Middle East and North Africa	.039	.030	.027	.014	.023	.013	.047	.095
South and Southeast Asia	.097	.032	.071	.077	.054	.025	.066	.176
East Asia	.053	.039	.087	.034	.075	.044	.068	.113
Sub-Sahara Africa	.048	.030	.023	.012	.002	.002	.040	.145
Developed countries	.725	.886	.827	.868	.905	.95	.799	.534
Less developed countries	.275	.114	.173	.132	.095	.05	.201	.466

* Chemistry, physics, biology. General science publication data provided by Professor Derek DeSolla Price of Yale University.

Europe, and Oceania have had relatively high levels of investment and high rates of productivity increase in their advanced agricultural sectors since 1950. Southern Europe has done less well. The Eastern European countries and Russia have expanded their agricultural research systems most rapidly and have achieved rapid production gains.

On the LDC side of the ledger, the case of Latin America is noteworthy. A number of countries in this region had developed quite "modern" agricultural sectors prior to the Second World War. Their economic performance in the past 20 years has been only partially successful. It is probably not merely coincidental that their agricultural research investment has been relatively low and shows little increase over time.

It also appears that in Africa and Asia, only South Asia (chiefly India and Pakistan) has been making some strides toward the development of a research system characteristic of growing and modernizing agricultural economies. Much of the Middle East investment is located in Israel. Most countries of Africa, the Middle East, and Southeast Asia have not developed research systems that even approach the standards set by the systems of the developed countries.

The picture that emerges from the extension data is quite different. In dollar terms, the LDCs appear to invest less than the developed countries, though the LDCs spend much more on extension than on research. When we make a comparison based on numbers of extension workers per dollar of production, however, the LDCs have a relatively high investment in extension, almost twice that of the developed countries. The emphasis on extension in the LDCs may make sense given the relative prices that they apparently pay for scientists and extension workers. Again, we cannot claim to know the optimal investment pattern, but the LDC combination of weak research systems and substantial extension systems does not appear to have been productive.

International Research Centers

In addition to the national research systems whose investment programs have been surveyed in the preceding tables, several international agricultural research centers have now been established. Table 6 summarizes data for the six centers existing in 1972. Only two of the centers, the International Maize and Wheat Improvement Center (CYMMT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines, have been in existence long enough to have had a significant impact on production. The high-yielding Mexican wheat and the "miracle" rice varieties were developed in these centers. Undoubtedly, the work done in these centers had a very significant impact, though it may be that recent discussions overemphasize their role and leave the erroneous impression that local domestic research systems, particularly in developing countries, have been totally ineffective.

The advantages of the centers are that they can attract outstanding scientists and provide them with scientific equipment, experimental fields, technical assistance, and an "environment" that cannot readily be provided

TABLE 6

INTERNATIONAL AGRICULTURAL RESEARCH CENTERS

International Center*	Location	Research Program Begun	1973 Budget ($000)	Commodity Emphasis
1. CYMMT ..	Mexico	1943 (1963)	5,172	Wheat (spring, dovum, triticals); maize
2. IRRI	Philippines	1962	2,800	Rice
3. CIAT	Columbia	1970	3,567	Foreign-beef production
4. IITA	Nigeria	1970	4,549	Cow peas, yams; cultivation system in the humid tropics
5. ICRISAT ..	India	1972	1,200	Grain sorghums, millet, pigeon peas, chick pear
6. CIP	Peru	1972	1,085	Potatoes

Proposed Centers	1977 Budget	1980 Budget
8. African Livestock Center (ILCA)	3,230	6,300
9. African Animal Disease Lab. (ILRAD)	3,050	3,500
10. West African Rice Research (WARDA).....	1,200	1,500
11. Soybean Improvement (INTSOY)	1,900	2,500
12. Others	...	...

NOTE.—Expected total budget of existing and proposed centers for 1980 is approximately $80 million.

* CYMMT: International Maize and Wheat Improvement Center; IRRI: International Rice Research Institute; CIAT: International Center of Tropical Agriculture; IITA: International Institute of Tropical Agriculture; ICRISAT: International Crops Research Institute for Semi-arid Tropics; CIP: International Potato Center.

in the national systems. They are not subject to the administrative and political constraints that inhibit the productivity of the national organizations. Perhaps the most important advantage of these centers lies in the scale of their operation.

The major disadvantage of the international centers is that they are very expensive. Expenditure per senior scientist in 1973 was in excess of $50,000 and approximated $100,000 in some of the centers. This generally exceeds the comparable expenditure for even the most expensive developed country systems. For example, in the United States, expenditures per scientist-man-year were approximately $70,000 in the animal sciences and $50,000 in the crop sciences in 1970.[6] The international centers would be roughly comparable to the most costly United States stations. The same research budget expended in national research systems in less developed countries would purchase at least twice as many scientist-man-years as the international centers do.

The Determinants of Agricultural Research

With the present very aggregative data, the analysis of the agricultural research system as an industry producing a capital good—knowledge—can only be preliminary and indicative. It is carried out on two aspects: the production function of knowledge and the demand for knowledge. The latter can be viewed both as an investment function, investment of the sector making use of the technical knowledge created, and as the funds allocation function—the agricultural research system is mainly publicly financed, and one may search for regularity in budget allocation.

The main factors in production of knowledge are manpower, scientific and technical; capital equipment; test plots; various current outlays; and knowledge. The last is a very important factor which enters the production process in several ways. Partly knowledge is embodied in the scientific manpower; partly it is directly transferred (Mexican wheat varieties transferred to India, for example); partly it is "borrowed" from other countries or disciplines to be used as an intermediate good in research.

The borrowing of knowledge from abroad cannot be analyzed here,[7] but the other major aspects of the production process of knowledge are brought forward in table 7. The general form of the "knowledge production function" estimated in the table is

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

where

$$P_j = \sum_{i=1}^{13} p_{ij},$$

[6] Robert E. Evenson and Finis Welch, "Research, Information, and Productivity in U.S. Agriculture," mimeographed (New Haven, Conn.: Economic Growth Center, Yale University).

[7] Evenson and Kislev, "Research and Productivity in Wheat and Maize."

TABLE 7

KNOWLEDGE PRODUCTION FUNCTION (EQ. [1])

	REGRESSIONS		
	(7a)	(7b)	(7c)
R^2	.840	.843	.907
Constant	1.183	1.115	1.195
Scientist-man-year (S)	.372 (3.11)	...	.378 (3.55)
Plant physiology (p_{14})	.426 (5.67)	.441 (6.55)	.565 (6.98)
Expenditures (E)	...	.341 (3.22)	...
GNP per capita (G)	...	...	.212 (1.00)
Newspapers per capita (N)	...	...	−.214 (1.24)

NOTE.—Dependent variable: number of publications in country (P_j). Data are averages for 1962–68. No. of observations: 44. In parentheses: t-values.

total number of publications in agricultural sciences (not including plant physiology) in country j, P_{ij} being publications in sector i in country j (the sectors are the 14 sectors listed above); S_j = scientific-man-years in agricultural research; E_j = expenditure on agricultural research; G_j = GNP per capita; N_j = number of newspapers per 10,000 people; and $f(\ )$ is a Cobb-Douglas function (the regressions were estimated in the double-log form). The interpretation of equation (1) is that knowledge (publications) is produced by researchers and by research budgets. The other variables in (1) stand for complementary factors: p_{14}—plant physiology work—is a measure of biological, nonagricultural research. Per capita GNP and the number of newspapers per 10,000 in the country's population are socio-economic and cultural factors that are sometimes alleged to affect the quality (i.e., the productivity) of research systems.

The production function was estimated (table 7) from a cross section of 44 countries; the observations were averages for the period 1962–68. Regressions (7a) and (7b) report the estimated elasticities of production with respect to number of scientists and to expenditures (multicollinearity prevented joining the two factors in one equation). In both equations plant physiology is an important and significant variable—the elasticity of this factor is larger than those of the other two. Plant physiology work is serving partly as a quality index for the agricultural scientist. "Quality" in the agricultural scientist is an understanding of fundamental biological, physical and social phenomena. The basic sciences are "productive," in the sense that fundamental research findings serve as "intermediate" inputs in mission-oriented research activity. Plant physiology research is probably serving as a proxy for the availability of university training (particularly at the graduate level) that is based on the biological and geoclimatic conditions of the country in question. It, of course, also represents a stream of new findings many of which enable the agricultural researcher to approach problems in new ways and with improved chances of success.

As regression (7c) in table 7 indicates, with plant physiology in the equation, the socioeconomic factors represented by G and N do not have a significant effect on productivity. Since high-income countries spend more on science, including biological sciences, the result in regression (7c) indicates that it is not the income and cultural level that affects productivity but the complementary effect of biological research.

The investment demand function (table 8) is estimated at the crop or subsector level. Publications on crop i in country j are explained by crop-level and country-level variables. The equation estimated is

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

where $f(\ )$ is again estimated in the double-log form. The newly defined variables are: q_{ij} = value of product i ($i = 1, \ldots, 11$) 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 β_i = a "product effect," a dummy variable measuring ease of publication or biases in counting in the product i.

Note that only 11 crops are included in the analysis; soil science and phytopathology are omitted.

As the regressions in table 8 indicate, larger product values entail more publications in the respective areas, but the elasticity is only of the

TABLE 8

INVESTMENT DEMAND FUNCTION (EQ. [2])

	Regressions		
	(8a)	(8b)	(8c)
R^2	.367	.466	.460
Constant	−1.545	−1.469	−1.918
Product (q)	.461	.404	.339
	(6.94)	(6.22)	(4.00)
Exports (Ex)	.165	.210	.181
	(4.50)	(5.68)	(4.25)
GNP per capita (G)	−.204	−.208	.927
	(.93)	(1.48)	(5.40)
Share of agriculture in GNP (H)	−.072	...	...
	(24)		
No. of agricultural workers (w)	...	...	.610
			(5.25)
Plant physiology (p_{14})	.304	.313	...
	(6.45)	(7.13)	
Dummies (β)	...	Yes	Yes

NOTE.—Dependent variable: publications in country by crop. Data are averages for 1962–68. No. of observations: 435. In parentheses: t-values.

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 colonial times. This may also be economically justified, as the demand for exports is elastic. A comparison of regression (8c) to (8b) reveals again the dominance of biological research over income as a productivity factor. The *number* of agricultural workers in regression (8c) is a measure of the absolute size of farm sector. The *share* in regression (8a) is a measure of its economic importance in the country. The signs of these two variables are what one would expect them to be, though the coefficient of H is very small and insignificant.

The inclusion of the dummies—the β_i's—in the regressions did not affect the other estimates substantially, but the dummies correct for biases resulting from errors in counting or differences in publication policies in different research fields.

Concluding Remarks

The chief purpose of the paper has been to provide summary information about decisions that nations have made regarding investment in research and related activities. The data show that in 1965 none of the LDC regions of the world had research systems that were on a par with developed country systems. On any comparative basis, they were investing less. Publications per scientist were lower as well, reflecting lower levels of graduate training, less complementary science activity, and different organizational features.

On the other hand, virtually all of the developed countries have in place substantial research systems, and have been investing roughly 1 percent of the value of agricultural products on research. Southern Europe has been intermediate with respect to research investment and economic performance in the agricultural sector. Eastern Europe has moved from low levels of investment to intermediate or high levels since the Second World War.

The LDCs have clearly given emphasis to extension and, by some comparisons, are investing more in extension effort than the developed countries (though the lack of data on private extension activity by agricultural supply firms is a major source of bias). Their move toward substantial extension programs and relatively weak research programs has been fostered and encouraged by technical and financial aid from developed countries. This bias in LDC investment is partly justified on the basis of relative prices for extension and research services, but appears to be largely based on the belief that technology in the developed countries can be transferred to the LDCs with those programs.

The regression results of the last section of the paper, while somewhat tentative in view of the data, have important policy implications. The finding that the productivity (measured by publication) of agricultural scientists is importantly affected by related research in plant physiology should at least serve to raise new questions about the proper research "mix." The view that less developed countries should have a research mix dominated by applied "adaptive" mission-oriented research may be quite in error. This, of course, presupposes that research publications are a good economic measure of the output of a research system. We develop substantial evidence elsewhere that they are.[8] On the other hand, it is possible that the output of research systems which is not directly measured by or related to publications is of greater economic significance than that reported in publications. We can only suggest that if it is, research systems which are capable of publishing are probably also quite capable of producing nonpublished output as well.

Appendix

AGRICULTURAL RESEARCH AND EXTENSION—COUNTRY DATA (1965)

	Research		Extension		Ratio of Research Expenditures to Value of Agricultural Product (%)	Research Expenditures per Farm (U.S. $)	Extension Workers per Farm	Publications in Agricultural Services (No. of Publications Abstracted in 1962–68)
	Expenditures (U.S. $000)	Scientist-Man-Years	Expenditures (U.S. $000)	Workers				
Austria	1,800	170	...	800	0.28	4.53	2.02	361
Belgium	9,260	650	...	292	1.19	34.42	1.09	529
Denmark	5,600	458	6,784	840	0.46	28.43	4.26	563
Finland	2,320	129	...	...	0.47	5.98	...	484
France	29,000	755	34,200	4,400	0.48	...	...	1,732
W. Germany	55,851	1,788	23,180	4,402	1.18	31.72	2.50	3,587
Greece	3,300	295	1,444	552	0.47	2.85	0.48	103
Ireland	6,700	328	2,400	502	1.43	18.61	1.39	158
Italy	13,000	853	14,122	3,082	0.40	3.03	0.72	1,856
Netherlands	27,700	820	4,500	1,898	2.33	92.03	6.31	1,643
Norway	6,480	495	6,062	652	2.70	14.93	1.50	377
Portugal	2,500	394	3,965	807	0.70	...	...	153
Spain	4,336	694	5,630	894	0.23	1.44	0.30	446
Sweden	11,000	408	5,800	610	1.40	41.51	2.30	858
Switzerland	5,800	392	1,730	406	1.62	...	...	571
U.K.	28,500	1,839	13,460	1,648	0.80	71.97	4.16	5,433
USSR	42,200	9,624	...	...	0.16	...	...	9,461
Yugoslavia	5,233	1,340	...	3,076	0.26	1.99	1.17	711
Canada	40,217	1,483	26,450	2,904	1.28	83.61	6.04	2,917
USA	350,000	13,800	178,000	6,233	0.81	94.34	1.68	21,092
Argentina	...	300	1,800	392	...	...	0.83	323
Bolivia	270	29	350	73	0.22	...	...	20
Brazil	4,500	520	...	603	0.09	1.34	0.18	440
Chile	1,300	223	300	122	0.43	...	...	188
Colombia	...	338	...	235	...	...	0.19	119
Costa Rica	579	76	...	166	...	8.91	2.55	...
Ecuador	1,370	87	1,645	320	0.53	...	...	14
El Salvador	584	56	885	70	0.32	2.61	0.31	17
Guatemala	300	15	...	94	0.13	0.72	0.23	59
Haiti	160	50	687	28	0.41	...	...	...
Mexico	1,837	231	250	300	1.73	1.35	0.22	259
Nicaragua	503	43	...	41	0.23	4.93	0.40	17
Panama	305	7	378	85	0.48	3.21	0.89	11
Paraguay	...	10	...	46	...	...	0.29	1
Peru	1,400	131	1,400	670	0.32	1.61	0.77	80
Uruguay	367	93	450	...	0.19	4.22	...	27
Venezuela	681	125	6,400	422	0.14	2.13	1.32	90
Libya	1,960	...	...	78	3.56	13.52	0.54	3
Sudan	4,798	82	...	18	0.94	...	...	124
UAR	9,200	400	...	...	0.60	5.60	...	357
Afghanistan	1,500	36	...	109	...	...	...	...
Cyprus	357	20	...	...	0.79	...	...	14

[8] Ibid.

Appendix (*Continued*)

Israel	7,000	403	...	...	3.17	...	...	491
Syria.........	440	15	...	...	0.16	...	...	0
Turkey.......	3,500	397	7,580	2,746	0.17	...	...	24
Burma	93	39	...	1,262	0.04	...	...	1
Ceylon	1,395	87	...	200	0.58	1.19	0.17	72
India	12,000	1,462	...	56,000	0.15	0.25	1.15	4,551
Indonesia.....	131	54	...	6,000	0.01	0.01	0.49	76
Japan	62,500	4,500	36,310	14,126	0.98	10.32	2.33	2,197
S. Korea	1,325	294	...	3,217	0.11	0.57	1.38	50
Malaysia	820	32	...	317	0.15	1.81	0.70	62
Nepal........	459	142	...	200	...	0.31	0.13	...
Pakistan......	5,014	654	6,037	9,000	0.23	0.41	0.74	410
Philippines ...	7,078	1,256	...	617	0.69	3.27	0.28	435
Taiwan.......	1,922	401	...	1,100	0.28	2.38	1.36	325
Thailand	8,428	442	...	502	1.13	2.62	0.16	36
S. Vietnam ...	547	40	...	95	0.25	0.29	0.05	19
Cameroon	800	32	...	310	0.38	...	...	11
Congo, Braz. .	233	29	...	...	...	2.08	...	...
Dahomey.....	1,292	18	...	...	2.53	...	...	20
Ethiopia......	...	30	308	1,204	...	...	...	12
Ghana	2,385	128	...	...	0.46	...	...	76
Kenya	...	123	4,608	5,277	...	...	...	184
Liberia.......	160	34	...	...	0.25	...	...	21
Malagasy Rep.	2,534	60	3,384	2,669	1.09	2.87	3.03	7
Malawi	966	48	1,288	778	...	...	...	...
Mali.........	625	21	...	...	0.95	2.23	...	0
Mauritius	1,050	71	...	...	...	...	...	...
Morocco	1,976	55	...	2,100	0.48	1.79	1.90	40
Mozambique..	1,000	42	...	...	...	...	...	...
Nigeria.......	3,354	335	...	18,050	0.17	...	...	205
Rwanda......	270	10	...	...	...	...	...	...
Senegal	1,851	51	...	...	1.16	6.27	...	20
Sierra Leone ..	165	23	...	...	0.16	...	...	16
Somalia	280	12	59	29	...	...	...	...
S. Africa	18,850	897	...	...	1.51	171.36	...	529
Rhodesia.....	...	165	...	...	...	...	...	139
Swaziland	175	11	...	...	...	...	...	...
Tanzania	1,288	51	...	2,455	0.41	...	...	88
Uganda	2,100	50	3,646	1,024	0.56	1.79	0.88	185
Upper Volta ..	225	9	...	...	0.30	...	...	8
Australia	56,364	2,085	...	...	2.11	223.67	...	2,347
New Zealand .	6,000	479	...	472	0.55	82.19	6.47	822

NOTE.—Ellipses indicate data not available.