The IARCs: Evidence of Impact on National Research and Extension and on Productivity

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The IARCs and Their Impact on National Research and Extension and on Productivity

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The first International Agricultural Research Center (IARC), IRRI, is now 25 years old. Several other IARCs[1/] have been in place for more than 15 years. A number of important changes have taken place, both in the development of the IARCs and in the building of national research and extension capacity in the developing world over this period[2/]. The first part of this paper provides a descriptive summary of national research and extension spending since 1959, the second reports findings that seek to determine whether the development of the IARC system has produced a measurable impact on the size and character of national agricultural research and extension programs; the third reports econometric estimates of the determinants of investment in national research and extension programs, especially as affected by the international system. The fourth section draws inferences regarding IARC impact on national spending. The fifth part specifies the econometric model relating investment to productivity and reports estimates and the sixth part discusses the policy implications of the productivity analysis.

I. A Descriptive Summary of National and International Program Development

National investment in agricultural research and extension programs has grown at an impressive rate in the past 25 years.[3/] Tables 1 and 2 summarize this investment; detailed national data are presented in Appendix 1. It may be

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Table 1: Agricultural Research Expenditures and Workers

	EXPENDITURES (000 Constant 1980 US$)			WORKERS (Scientist-Years)		
	1959	1970	1980	1959	1970	1980
REGION/SUBREGION						
Western Europe	274,984	918,634	1,489,588	6,251	12,547	19,540
Northern Europe	94,718	230,135	409,527	1,818	4,409	8,027
Central Europe	141,054	563,334	871,233	2,888	5,721	8,827
Southern Europe	39,212	125,165	208,828	1,545	2,417	2,686
Eastern Europe and USSR	568,284	1,282,212	1,492,783	17,701	43,709	51,614
Eastern Europe	195,896	436,094	553,400	5,701	16,009	20,220
USSR	372,388	846,118	939,383	12,000	27,700	31,394
North America and Oceania	760,466	1,485,043	1,722,390	8,449	11,683	13,607
North America	668,889	1,221,006	1,335,584	6,690	8,575	10,305
Oceania	91,577	264,037	386,806	1,759	3,113	3,302
Latin America	79,556	216,018	462,631	1,425	4,880	8,534
Temperate South America	31,088	57,119	80,247	364	1,022	1,527
Tropical South America	34,792	128,958	269,443	570	2,698	4,840
Caribbean and Central America	13,676	29,941	112,941	491	1,160	2,167
Africa	119,149	251,572	424,757	1,919	3,849	8,088
North Africa	20,789	49,703	62,037	590	1,122	2,340
West Africa	44,333	91,899	205,737	412	952	2,466
East Africa	12,740	49,218	75,156	221	684	1,632
Southern Africa	41,287	60,752	81,827	696	1,091	1,650
Asia	261,114	1,205,116	1,797,894	11,418	31,837	46,656
West Asia	24,427	70,676	125,465	457	1,606	2,329
South Asia	32,024	72,573	190,931	1,433	2,569	5,691
Southeast Asia	9,028	37,405	103,249	441	1,692	4,102
East Asia	141,469	521,971	734,694	7,837	13,720	17,262
China	54,166	502,491	643,555	1,250	12,250	17,272
WORLD TOTAL	2,063,553	5,358,595	7,390,043	47,163	108,510	148,039

Sources: Boyce, J. K. and R. E. Evenson, National and International Agricultural Research and Extension Programs. (New York: The Agricultural Development Council, 1975); and M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University, Economic Growth Center, 1983).

Table 2: Agricultural Extension Expenditures and Workers

	EXPENDITURES (000 Constant 1980 US$)			WORKERS (Scientist-Year)		
	1959	1970	1980	1959	1970	1980
REGION/SUBREGION						
Western Europe	234,016	457,675	514,305	15,988	24,388	27,881
Northern Europe	112,983	187,144	201,366	4,793	5,638	6,241
Central Europe	103,082	199,191	236,834	7,865	13,046	14,421
Southern Europe	17,950	71,340	76,105	3,330	5,704	7,219
Eastern Europe and USSR	367,329	562,935	750,301	29,000	43,000	55,000
Eastern Europe	126,624	191,460	278,149	9,340	15,749	21,546
USSR	240,705	371,475	472,152	19,660	27,251	33,454
North America and Oceania	383,358	601,950	760,155	13,580	15,113	14,966
North America	332,892	511,883	634,201	11,500	12,550	12,235
Oceania	50,466	90,067	125,954	2,080	2,563	2,731
Latin America	61,451	205,971	396,944	3,353	10,782	22,835
Temperate South America	5,741	44,242	44,379	205	1,056	1,292
Tropical South America	47,296	136,943	294,654	2,369	7,591	16,038
Caribbean & Central America	8,414	24,786	57,911	779	2,135	5,505
Africa	237,883	481,096	514,671	28,700	58,700	79,875
North Africa	84,634	176,498	172,910	7,500	14,750	22,453
West Africa	53,600	181,324	204,982	9,000	22,000	29,478
East Africa	39,496	86,096	106,030	9,000	18,750	24,211
Southern Africa	60,153	37,178	30,749	3,200	3,200	3,733
Asia	143,876	412,937	507,113	86,900	142,500	148,780
West Asia	28,211	97,315	119,780	7,000	18,800	16,535
South Asia	56,422	87,727	82,194	57,000	74,000	80,958
Southeast Asia	19,747	55,441	63,959	9,500	30,500	33,987
East Asia	39,496	172,454	241,180	13,400	19,200	17,300
China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
WORLD TOTAL	1,427,913	2,722,564	3,443,489	177,521	294,483	349,337

Sources: Boyce, J. K. and R. E. Evenson, National and International Agricultural Research and Extension Programs. (New York: The Agricultural Development Council, 1975); and M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University, Economic Growth Center, 1983).

seen that, in 1980 constant dollars, research spending in developing countries increased from 1959 to 1980 by a multiple of 5.8 in Latin America, 6.9 in Asia, and 3.6 in Africa. The comparable spending multiples for extension investment were 6.4 for Latin America, 3.5 for Asia, and 2.2 for Africa. Scientist-year (SY) multiples were lower than spending multiples (6.0 for Latin America, 4.1 for Asia, 4.2 for Africa), reflecting rising real costs per SY. (For extension workers the multiples were 6.8 for Latin America, 1.8 for Asia, 2.9 for Africa).

Table 3 shows how research and extension "spending intensities", i.e., spending as a percent of the domestic value of agricultural product (G.D.P.) has changed from 1959 to 1980. These data show that in 1959 the low-income and middle-income developing countries were approximately twice as spending intensive for extension as for research.[4/] The reverse was true for the industrialized countries. The rapid growth in spending intensities for research from 1959 to 1980 combined with little or no growth in extension intensities in the 1970s, produced roughly equal spending intensities for research and extension in most developing countries.

Table 4 provides comparable data for "worker intensities" (i.e. ratios of workers to G.D.P.). For research, the same general pattern reflected in spending intensities is reflected in the workers intensities. Because spending per SY is lower in developing countries, they fare better by this measure. The difference between the low-income and industrialized countries is much reduced.

For extension, the picture is quite different. By 1959 low-income developing countries had attained very high extension intensities; 5 to 7 times greater than those attained in industrialized countries. By 1980, with a slight decline in these intensities for industrialized countries, the difference was even greater. Middle-income and semi-industrialized countries

Table 3: Research & Extension Expenditures as a Percent of the Value of Agricultural Product

	Public Sector Agricultural Research Expenditures			Public Sector Agricultural Extension Expenditures		
Subregion	1959	1970	1980	1959	1970	1980
Northern Europe	.55	1.05	1.60	.65	.85	.84
Central Europe	.39	1.20	1.54	.29	.42	.45
Southern Europe	.24	.61	.74	.11	.35	.28
Eastern Europe	.50	.81	.78	.32	.36	.40
USSR	.43	.73	.70	.28	.32	.35
Oceania	.99	2.24	2.83	.42	.76	.98
North America	.84	1.27	1.09	.42	.53	.56
Temperate South America	.39	.64	.70	.07	.50	.43
Tropical South America	.25	.67	.98	.34	.71	1.19
Caribbean & Central America	.15	.22	.63	.09	.18	.33
North Africa	.31	.62	.59	1.27	2.21	1.71
West Africa	.37	.61	1.19	.58	1.24	1.28
East Africa	.19	.53	.81	.67	.88	1.16
Southern Africa	1.13	1.10	1.23	1.64	.67	.46
West Asia	.18	.37	.47	.25	.57	.51
South Asia	.12	.19	.43	.20	.23	.20
Southeast Asia	.10	.28	.52	.24	.37	.36
East Asia	.69	2.01	2.44	.19	.67	.85
China	.09	.68	.56	n.a.	n.a.	n.a.
Country Group*						
Low-Income Developing	.15	.27	.50	.30	.43	.44
Middle-Income Developing	.29	.57	.81	.60	1.01	.92
Semi-Industrialized	.29	.54	.73	.29	.51	.59
Industrialized	.68	1.37	1.50	.38	.57	.62
Planned	.33	.73	.66	-	-	-
Planned - excluding China	.45	.75	.73	.29	.33	.36

*For definition of Country Groups see Note 2

Sources: Appendix Tables 1 ans 2 and USDA, Indices of Agricultural Production, various issues.

Table 4: Research and Extension Worker Relative to the Value of Agricultural Product

	SY's Per 10 Million (Constant 1980) Dollars Agricultural Product			Extension Workers per 10 Million (Constant 1980) Dollars Agricultural Product		
Subregion	1959	1970	1980	1959	1970	1980
North Europe	1.05	2.01	3.14	2.76	2.56	2.61
Central Europe	.80	1.21	1.56	2.19	2.77	2.73
Southern Europe	.93	1.17	.96	2.00	2.76	2.69
Eastern Europe	1.44	2.97	2.84	2.36	2.88	3.13
USSR	1.38	2.37	2.34	2.26	2.33	2.50
Oceania	1.91	2.64	2.43	2.26	2.17	2.11
North America	.84	.89	.84	1.44	1.31	1.08
Temperate South America	.46	1.15	1.32	.26	1.19	1.26
Tropical South America	.41	1.41	1.77	1.71	3.95	6.46
Caribbean & Central America	.53	.86	1.20	.82	1.53	3.12
North Africa	.91	1.44	4.24	18.83	28.45	22.23
West Africa	.33	.61	1.42	7.61	14.01	18.08
East Africa	.32	.77	1.76	16.28	22.41	26.64
Southern Africa	1.90	1.96	2.47	8.73	5.94	5.62
West Asia	.33	.84	.88	4.39	7.25	6.54
South Asia	.50	.65	1.29	20.83	19.51	19.53
Southeast Asia	.47	1.28	2.07	9.81	13.07	19.72
East Asia	3.80	5.29	5.72	6.57	7.05	6.13
China	.22	1.66	1.49	n.a.	n.a.	n.a.
Country Group						
Low-Income Developing	.43	.67	1.40	18.14	18.61	20.43
Middle-Income Developing	.69	1.31	2.40	8.89	14.68	15.98
Semi-Industrialized	.70	1.21	1.36	2.80	4.95	5.21
Industrialized	1.24	1.71	1.85	2.37	2.31	2.12
Planned	1.02	2.27	2.13	-	-	-
Planned excluding China	1.40	2.54	2.50	2.29	2.49	2.63

Sources: Appendix Table

also increased their extension intensities.

These worker intensities should not be interpreted as if there were no differences in the quality of workers among countries. There is little doubt that the general levels of training of both scientists and extension workers vary between countries and are lower in the developing countries. However, the differences are not as great as is generally supposed. There is also little indication that these differences have changed as research and extension spending has increased. These data do not include "extension type" spending associated with Rural Development Projects in developing countries. Were such data to be tabulated and included as extension spending, the magnitude of the differences in spending on extension relative to research in the developing countries would be even greater.

Table 5 provides further insight into the motivation for the high extension worker intensities in developing countries. It shows expenditure/worker ratios for research and extension. These ratios include salaries of scientists and extension workers and related costs, including laboratory costs and the costs of technicians. The ratio of research costs to extension costs is as much as 20 to 1 for the low-income developing countries and only 3 to 1 or so for the industrialized countries. Some of this difference is a quality difference (extension workers have quite advanced training in most industrialized countries and may have little training in low-income countries), and some is due to real cost differences. Many low-income countries do not have the capacity to train agricultural scientists and must incur high costs to train researchers and to purchase scientific equipment.

Table 6 reports data on spending by commodity in the form of spending intensities. With few exceptions, developing countries cannot provide a commodity breakdown for their research spending. They do well to provide data

Table 5: Expenditures per SY/Extension Worker

Region/Subregion	Research Expenditures per SY (000 Constant 1980 US$)			Extension Expenditures per Extension Worker (000 Constant 1980 US$)		
	1959	1970	1980	1959	1970	1980
Western Europe	44	73	76	15	19	18
Northern Europe	52	52	51	24	33	32
Central Europe	49	98	99	13	15	16
Southern Europe	25	52	78	5	13	11
Eastern Europe & USSR	32	29	29	13	13	14
Eastern Europe	34	27	27	14	12	13
USSR	31	31	30	12	14	14
North America & Oceania	90	127	127	28	40	51
North America	100	142	130	29	41	52
Oceania	52	85	117	24	35	46
Latin America	56	44	54	18	19	18
Temperate South America	85	56	53	28	42	34
Tropical South America	61	48	56	20	18	18
Caribbean & Central America	28	26	52	11	12	11
Africa	62	65	53	8	8	6
North Africa	35	44	27	11	12	8
West Africa	108	97	83	6	8	7
East Africa	58	72	46	4	5	4
Southern Africa	59	56	50	19	12	8
Asia	23	38	39	2	3	3
West Asia	53	44	54	4	5	7
South Asia	22	28	34	1	1	1
Southeast Asia	20	22	25	2	2	2
East Asia	18	38	43	3	9	14
China	43	41	37	n.a.	n.a.	n.a.
Country Group						
Low-Income Developing	34	40	47	2	2	2
Middle-Income Developing	42	44	47	7	7	6
Semi-Industrialized	41	45	46	10	10	11
Industrialized	55	80	93	16	25	29
Planned	33	32	31	-	-	-
Planned excluding China	31	25	30	13	13	14

Sources: See Tables 1 and 2.

Table 6: Research as a Percent of the Value of Product, by Commodity, Average 1972-79 Period, 25 Countries

COMMODITY	REGION				Spending by International Centers	Ratio IARC Spending to Total
	Africa	Asia	Latin America	All Countries		
Wheat	1.30	.32	1.04	.51	.02	.04
Rice	1.05	.21	.41	.25	.02	.07
Maize	.44	.21	.18	.23	.03	.11
Cotton	.23	.17	.23	.21	-	-
Sugar	1.06	.13	.48	.27	-	-
Soybeans	23.59*	2.33	.68	1.06	-	-
Cassava	.09	.06	.19	.11	.02	.15
Field Beans	1.65	.08	.60	.32	.04	.11
Citrus	.88	.51	.57	.52	-	-
Cocoa	2.75	14.17*	1.57	1.69	-	-
Potatoes	.21	.19	.43	.29	.08	.21
Sweet Potatoes	.06	.08	.19	.07	-	-
Vegetables	1.56	.41	1.13	.73	-	-
Bananas	.27	.20	.64	.27	-	-
Coffee	3.12	1.25	.92	1.18	-	-
Groundnut	.57	.12	.60	.25	.005	.02
Coconut	.07	.03	.10	.04	-	-
Beef	1.82	.65	.67	1.36	.02	.02
Pork	2.56	.39	.60	1.25	.02	.02
Poultry	1.99	.32	1.12	1.64	-	-
Other Livestock	1.81	.89	.42	.71	-	-

Sources: M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University, Economic Growth Center, 1983); and USDA, Indices of Agricultural Production, various issues.

(*) Ratios are high because production is very low.

on total spending. It is possible, however, to obtain publications data from the CAB Abstract system by commodity orientation. This was done for each of 25 countries for 2 periods 1972-5 and 1976-80. These data were then standardized into equal cost units utilizing Brazilian data. For Brazil real spending by commodity and CAB publications data were available. It was thus possible to standardize publications into cost equivalent units. Standardized publications were then used to allocate actual expenditures to commodities.

The data show that spending intensities differ greatly by commodity in the 25 country sample (these 25 countries account for approximately 90 percent of total production in developing countries, excluding China). Spending intensities are low for coconuts, sweet potatoes and cassava and high for cocoa, coffee and livestock. The table also shows that the IARCs account for relatively low shares of the total research on the commodities they work on. Since expenditures per SY are very high in the IARCs (about 4-6 times the average for national spending), the IARCs are much less significant in terms of their share of scientific manpower devoted to these commodities.

Table 7 utilizes the CAB publications data to form ratios of "basic" to "applied" research. Abstracting journals are classified as to whether they are oriented to relatively basic research fields or to relatively applied fields (see the notes to the table for the classification). While this procedure is very crude it does provide a basis for comparing the research programs of developing countries with the research programs of developed countries. The table shows that the 25 developing countries have slightly higher ratios of basic to applied research on crops and substantially higher ratios of basic to applied research on animals.

II. Specifying the Determinants of Investment in Research and Extension

If IARC impacts on national research and extension spending are to be

Table 7: Ratios of Basic to Applied Research

	Crop Research			Animal Research		
	1972-75	1976-79	1980-83	1972-75	1976-79	1980-83
Argentina	.13	.16	.08	.33	.59	.90
Brazil	.18	.19	.17	.66	.97	.91
Chile	.13	.13	.14	.38	.47	.59
Colombia	.15	.17	.22	.34	.61	.90
Mexico	.16	.10	.07	.32	.61	.90
Peru	.25	.49	.26	.23	.15	.44
Venezuela	.18	.14	.12	.51	.95	1.40
Ghana	.12	.07	.12	.25	.48	.53
Kenya	.15	.16	.18	.23	.71	.96
Nigeria	.14	.22	.19	.32	.59	.64
Sudan	.12	.04	.13	.58	.53	.60
Tanzania	.04	.07	.13	.93	1.11	1.11
Tunisia	.09	.05	.07	.57	1.18	2.10
Uganda	.10	.06	.23	.29	.97	1.79
Egypt	.14	.16	.16	.30	.41	.50
Sri Lanka	.08	.09	.09	.33	.36	.26
India	.21	.27	.26	.29	.43	.38
Indonesia	.05	.10	.08	.64	.92	.43
South Korea	.14	.15	.19	.58	.43	.61
Malaysia	.22	.21	.17	1.07	.61	.51
Pakistan	.10	.08	.09	.36	.43	.43
Philippines	.19	.16	.15	.51	.37	.30
Taiwan	.17	.29	.27	.76	.42	.30
Thailand	.17	.16	.18	1.37	1.97	2.68
Turkey	.41	.40	.28	.47	.73	.50
25 Developing Countries	.18	.22	.21	.37	.52	.54
All Developed Countries	.16	.15	.16	.23	.34	.30

Note: Ratios are based on counts of abstracted publications by class of journal defined as follows.

Basic Crop Journal: Helminthological Abstracts (B); Rev. Plant Pathology

Applied Crop Journals: Field Crops Abstracts, Herbage Abstracts, Horticultural Abstracts, Review of Applied Entomology, Soils and Fertilizers, Wood Abstracts.

Basic Animal Journal: Helminthological Abstracts, Protozoologist Abstracts, Review of Med. & Vet. Mycology

Applied Animal Journals: Animal Breeding Abstracts, Dairy Science Abstracts, Nutrition Abstracts (land and feeding), Rev. Applied Entomology (A), Vet. Bulletin and Index Vet.

measured a specification relating national spending to "determinants", including IARC investment, is required. Such a specification should be consistent with economic logic and political reality. Since IARC investments are commodity based, it is natural to develop the specification for spending by commodity.

The specification developed here is motivated by a project evaluation or planning perspective modified by political constraints. The specification includes variables that a rational planner would use to guide optimal investment. It also includes variables that reflect the political power of interest groups and political constraints.

Before discussion of the specification it will be useful to discuss the data to be utilized and to list the variables in the data. Two data sets have been constructed.

The first is a data set where the observations are for two periods, 1972-5 and 1976-80 for 24 countries.[5/] For this data set it was possible to obtain aid variables, thus allowing a test of the role of aid in influencing national spending. The second data set is for the same countries, for a reduced set of variables measured annually for the 1962-82 period.

The observations in both data sets are on commodities (i.e., an observation is for a commodity, a country and a year) (or an average of 1972-5 or 1976-80 for the first data set). The field crop commodities are rice, wheat, maize, sorghum, millets, cassava, field beans, potatoes, sweet potatoes, groundnuts, sugar and soybeans, livestock and horticultural crops include bananas, coffee, coconut, beef, pork, poultry and other livestock.

Table 8 provides a list of the variables for the two data sets with a short definition of the variable. Those variables marked with an asterisk are measured on a country rather than a commodity basis. That is, they are common

Table 8: Variables Dictionary: Research and Extension Investment Analysis

	1972-5, 1976-80 Data		1962-82 Data	
	Mean	Std. Dev.	Mean	Std. Dev.
I. Endogenous (Choice) Variables				
RES: Annual Spending (millions of 1980 dollars) by Commodity on Research	.9819	2.24	0.69	1.70
EXTEXD: Annual Spending (millions of 1980 dollars) on Extension (all commodities	30.68	41.95	26.50	39.60
II. Partially Endogenous Variables				
AID: Value of Aid from all Sources (millons of 1980 dollars)	25.00	17.67	n.a.	
NDONORS: The Number of Donors Providing Aid to Research	4.92	2.93	n.a.	
WBRES: World Bank supported Research Programs (including national commodity)	10260	93445		
WBEXT: World Bank Supported Extension Programs (including national components	10333	67300		
NHSTAFF; Number of IARC Scientists in Countries other than IARC Host Countries	3.88	3.52		
INTCR: Number of Joint IARC-Joint IARC-National Research Collaborative Research Agreements	.27	1.44		
BASIC: Ratio of Non-commodity Oriented Research to Commodity Research (See Table 7)	24.97	6.84		
CONGRU: A measure of Congruence Between Research Spending and Commodity Value $CONGRU = 1 - \sum (V_i - C_i)^2$ where V_i is research share, C_i is Commodity share	.85	.13		
III. Exogenous Variables				
A. Economic				
PROD: Value of Commodity Production (millions of 1980 dollars)	223.34	653.63	2113.62	8452.20
DIVER: Inverse of the Sum of Squared shares of Production in Commodity Geo-Climate Combinations	0.4118	.21	0.39	0.20
EXPRAT: Ratio of Expenditures per SMY to Expenditures per Extension Worker	10.14	9.99	9.44	9.10
ARABLE: Ratio of Arable Land in the Current Period to Arable Land Six Years Earlier	1.09	.11	1.05	0.10
CINTSP: Cumulated Research expenditures on the Commodity in IARC's (millions of 1980 dollars)	6.17	13.78	4580.59	10148.80
B. International Transfer				
RESNSR: Research Scientist Manyears on the commodity by Neighboring Countries in similar Geo-climate regions (millions of 1980 dollars)	8.67	12.61	5.14	7.60
INTLOC: A Dummy Variable = 1 if the country is hosting the IARC undertaking research on the commodity	.019	.14	n.a.	
TOTALAREA: Total in crops in the country (000 ha)	10715.19	20902.44	10740.77	21558.60
C. Political - Economic				
IMPORTS: Value of Imports of the Commodity (millions of 1980 dollars)	16.39	71.68	n.a.	
EXPORTS: Value of Exports of the Commodity (millions of 1980 dollars)	24.46	100.75	n.s.	
UREARICE: Ratio of Prices Paid by Farmers for Urea Fertilizer to Prices received for rice	2.74	1.61	2.76	1.70
ECONAG: Percent of Economically Active Population Working in Agriculture	54.45	19.77	56.62	20.20
URBANPOP: Percent of the Total Population Living in Urban Areas of 100,000 population or more	34.53	21.58	32.05	21.10
VIOLD: Percent of Population Killed in Domestic Political Violence in Past Decade	.12(-10)	.12(-9)	0.00	0.00
D. Other				
T1: A Dummy Variable = 1 if time period is 1972-75	0.55	0.5	n.a.	
R1: A Dummy Variable = 1 is Country is Located in Asia	0.4	0.49	n.s.	
R2: A Dummy Variable = 1 if Country is Located in Africa	0.32	0.47	n.a.	

to all commodities (accordingly their means are not comparable to the means of variables actually measured on a commodity basis.)

The variables are classified as endogenous, i.e., the choice variables being subject to analysis, partially endogenous, and exogenous. The exogenous variables are further classified as "economic" variables, "international transfer" variables, and "political-economic" variables.

The dependent variables in the analysis are the variable measuring national research spending and national extension spending.

RESEXP (measured in millions of 1980 dollars).

EXTEXP (measured in millions of 1980 dollars. This variable is not measured on a commodity basis).

The model by which this spending is determined is constructed in stages. The first stage is motivated by supposing that a planner is attempting to maximize the economic surplus, (i.e., both consumers' and producers' surplus) associated with the research or extension program. In the second stage the planner takes international transfer conditions into account. In the third, the planner takes political constraints into account. (This is the rationale for the classification of exogenous variables in Table 8.)

Before discussing these variables, it should be noted that several aid variables, AID, NDONORS, WBEXT, WBRES NHSTAFF, and INTCR are also included in the model. These cannot be considered to be exogenous determinants of national spending, however, since actions by the recipient countries as well as choices by donors responding to characteristics of recipient countries determine this spending. Thus these aid variables must be regarded to be simultaneously determined along with national spending. (See the following section for a discussion of the econometric treatment.)

Now consider the first stage of the planner's problem. A given research program can be expected to lower production costs per unit of production. The more units over which costs can be lowered, the higher the optimal level of research. Each commodity and each geo-climate region present different research problems to some degree. Hence units of production should be measured on a commodity-region basis. The two variables PROD (production) and DIVER (diversity) (and the interaction of these two variables) are designed to pick up these effects.[6] National research spending is expected to rise as both production and diversity increase.

For some (perhaps most) research programs a "minimum critical mass" of research effort may be required for an effective program. If so there will be a threshold level of production below which a research program cannot be justified. Small diverse countries are more likely than larger countries to face these problems.

The variables EXPRAT and ARABLE are price variables reflecting prices of alternative sources of growth in supply. EXPRAT, the ratio of expenditures per SY to expenditures per extension worker, is designed to reflect the relative costs of pursuing growth through extension investment. (Expressing it in ratio terms avoids the need to specify an exchange rate.) It is expected that when the price of research resources falls relative to extension resources more spending in research will take place. The ARABLE variable (the ratio of arable land currently to arable land six years previously) is designed to reflect the price of supply growth via land expansion. When the change in arable land is small, reflecting land exhaustion, more spending on research is expected.

Now turn to the second stage of the problem. The planner recognizes that technology may "spill-in" from other countries and from IARCs. He also recognizes, however, that the potential spill-in technology was designed for or "targeted" to geo-climate conditions in other countries. Other national programs will be targeting their research programs to their own geo-climate conditions. The IARCs may target to a broader range of conditions than are extant in their host countries, but in practice they lack the resources to provide technology targeted to more than a limited range of environments. Thus, the planner will find that some technology available on the international market is directly suited to use (i.e., it is targeted to domestic conditions) but that much new technology (and related research findings) is "mismatched", i.e., it is targeted to geo-climate conditions differing from those of the country. It is hypothesized that the planner's response to closely matched technology from abroad will be to reduce domestic research investment since domestic research is a substitute for matched technology from abroad (extension spending may be inversed). Likewise, the planner's response to mismatched technology from abroad may be to increase domestic research investment since this mismatched technology offers domestic researchers an opportunity for modification and adaptation of the mismatched technology to domestic conditions. Of course, if the mismatch is too great it will not offer such opportunities.

We would then expect planners to exhibit a mixed response to technology from abroad. On the one hand, they will "free ride" on the research of IARCs and neighboring countries to the extent that they see these research units as producing closely matched technology with little scope for adaptation. On the other hand, they will respond with increased adaptive research to the extent that they see these units producing mismatched technology offering adaptation opportunities and to the extent that these units are producing "pre-technology" scientific discoveries that also enhance the productiveness of their own systems.

The variables CINTSP, (cumulated spending in IARCs on the commodity) and

RESNSR, (SYs working on the commodity in geo-climate neighboring countries) are measures of the programs that a national planner will respond to. Whether the response will be a net negative free-riding response or a net positive adaptive opportunity response depends on the nature of the technology. The variable TOTALAREA is a measure of the size of the country and the interaction of this variable with CINTSP is designed to identify whether the response to IARC investment differs for large and small countries.

Finally, the planner will respond to political constraints. The variables IMPORT and EXPORT measure the effects of international trade. Most countries implicitly place a higher value on international exchange than on domestic production. A unit of product that saves or earns foreign exchange is valued more highly than one that does not. A planner will respond to this by investing more in research on commodities that save or earn foreign exchange. Many countries intervene in agricultural markets. The UREARICE variable (the ratio of prices paid for urea fertilizer to prices raised for rice) is a measure of this intervention. A planner might attempt to "compensate" for some types of intervention by spending more or less on research.

The variables, ECONAG, URBANPOP and VIOLD, are crude proxies for political organization as well as for interest group power. A planner will respond to pressure from interest groups, for example to urban pressure groups by shifting resources from research to competing investments even though urban consumers are the major beneficiaries of agricultural research.7/ High proportions of the labor force in agricultural are usually associated with weak political power of rural people. If so, this could reduce spending on research and extension.

These political variables, it should be noted, are proxies for many different combinations of interests and the ability to translate these interests into political action. In the absence of a political model little interpretation can be given to measured impacts. The justification for the inclusion of these variables in the model is simply that they may control for some difference in political conditions and reduce bias in the estimated parameters that can be given stronger interpretations.

III. Econometric Estimates: Investment Analysis

Table 8 lists the variables discussed above. The actual specification requires a procedure for handling the partially endogenous variables, basically the Aid variables. In addition the functional form has to be specified.

The two period data set (set 1) does not have sufficient observations to estimate investment relationships for each commodity. It does contain aid variables and is suited to a general analysis of research investment based on pooled commodity observations. The second data set for the 1962-82 period does contain sufficient observations to enable an analysis of determinants of spending for each commodity and for extension spending as well. It does not contain aid variables.

Aid Determinants - Two Period Data

The specification for the two period data set and for the aid analysis is considered first. This specification requires that national research spending and aid be treated as simultaneously determined. A Two Stage Least Squares procedure is appropriate. The endogenous variables are: AID, NDONORS, NHSTAFF, WBRES, WBEXT, INTCR, CONGRU, BASIC, EXTEXP, and RESexp. The latter two variables are the most important from the perspective of this analysis. the model treats each of the first 8 variables as dependent on both EXTEXP and RESEXP in addition to a number of exogenous variables. EXTEXP and RESEXP are treated as dependent only on aid (AID or WBRES and WBEXT) and a different set of exogenous variables.

The econometric estimates based on this model are reported in Tables 9 and 10. Table 9 reports the results for the aid variables and for characteristics of national systems. Table 10 summarizes the main results showing determinants of investment in field crop research, livestock and horticultural crop research and in extension.

The functional form used is linear except that several multiplicative or interaction variables are used. These are:

PROD2 = PROD x PROD
PRDDIVER = PROD x DIVER
PRDXPORT = PROD x EXPORTS
PRDMPORT = PROD x IMPORTS
INTSPLOC = INTLOC x CINTSP
AREACINT = TOTALAREA x CINTSP

The B001 notation identifies the endogenous variables in each equation

In Table 9, national research spending, RES, and extension spending EXTEXP are the endogenous variables treated in determining aid flows and characteristics of national research systems (these variables are predicted in Table 10). As the table shows, aid agencies do appear to respond to national investment in extension but not to investment in research. Higher extension spending appears to reduce both the aid level to agricultural research and the number of donors providing that aid. A measure of general aid to extension is not available but the results do show that World Bank aid to extension reponds positively to national spending levels. (Of course, as Table 10 shows national spending responds positively to World Bank support as well. The two stage least squares procedure is designed to identify the separate causal relationship). Higher extension spending also appears to induce research programs with higher fractions of non-commodity oriented components.[8/] It also induces more IARC aid in the form of non-host staffing.

The positive TOTALAREA and negative AREADIV coefficients in the AID, NDONORS, WBRES and WBEXT equations show that aid agencies respond negatively to

Table 9
Estimated Coefficient and Statistics of Two-Stage Least Squares Equations for Determinants of Aid*

Independent Variable	AID	NDONORS	WBRES	WBEXT	NHSTAFF	INTCR	BASIC	CONGRU
				DEPENDENT VARIABLE				
Intercept	21.541 (2.02)	6.93 (4.49)	-44.15 (2.55)	-39.45 (1.46)	4.70 (2.36)	2.22 (1.76)	13.38 (3.38)	.264 (4.17)
B001.RES*	.830 (1.27)	.022 (.23)	1.31 (1.24)	.305 (.18)	.112 (.92)	-.010 (.13)	.191 (.78)	.0009 (.24)
B001.EXTEXP*	-.298 (5.49)	-.018 (2.30)	-.063 (.71)	.316 (2.29)	.050 (4.91)	-.011 (1.71)	.087 (4.35)	-.0001 (.30)
TOTLAREA	.003 (10.46)	.0002 (5.49)	.003 (6.72)	.004 (5.53)	-.0003 (6.10)	.00005 (1.49)	-.0008 (6.84)	$1x10^{-6}$ (.54)
AREADIV	-.010 (9.65)	-.0008 (5.63)	-.010 (6.18)	-.014 (5.44)	.001 (6.72)	-.0002 (1.43)	.0025 (6.89)	$1x10^{-6}$ (.24)
UREARICE	-3.070 (4.88)	-.328 (3.61)	-4.82 (4.73)	1.96 (1.23)	.115 (.98)	.057 (.76)	2.48 (10.67)	.008 (2.26)
ARABLE	-12.972 (1.88)	5.83 (5.86)	5.94 (.53)	46.52 (2.66)	-.097 (.08)	.618 (.76)	10.35 (4.06)	.035 (.87)
ECONAG	.595 (4.50)	-.048 (2.49)	.946 (4.41)	.099 (.028	-.024 (.96)	-.029 (1.83)	-.180 (3.66)	.005 (6.88)
URBANPOP	.119 (1.12)	-.131 (8.49)	.423 (2.45)	-.195 (.72)	-.047 (2.39)	-.019 (1.55)	-.016 (.41)	.007 (11.40)
VIOLD	5547.1 (.66)	2637.9 (2.22)	24723 (1.85)	68422 (3.27)	5399.7 (3.51)	-1200.7 (1.23)	22495 (7.38)	90.88 (1.86)
INTLOC	5.766 (1.40)	.510 (.86)	-2.94 (.44)	15.24 (1.46)	1.54 (2.01)	3.09 (6.35)	-5.29 (3.47)	-.048 (1.98)
CINTSP	-.005 (.11)	.0015 (.23)	-.035 (.46)	.066 (.56)	-.005 (.62)	.003 (.51)	.050 (2.44)	.0005 (1.48)
AREACINT	$-4x10^{-7}$ (.23)	$-4x10^{-8}$ (.13)	$-8x10^{-7}$ (.24)	$8x10^{-6}$ (1.55)	$-1x10^{-7}$ (.33)	$1x10^{-6}$ (5.49)	$-3x10^{-8}$ (.04)	$-4x10^{-9}$ (.32)
EXPRAT	-.675 (4.35)	-.010 (.48)	-.563 (2.24)	-.322 (.82)	.003 (.10)	-.031 (1.71)	.151 (2.62)	-.0008 (.88)
RESNSR	-	-	-	-	-	-	-.116 (3.16)	-.001 (1.89)
F	23.55	29.53	24.03	37.68	10.42	9.33	15.64	22.24
R^2	.384	.438	.388	.4989	.216	.198	.308	.388

*Absolute values of asymptatic t-ratios in parentheses
The B001 rotation indicates that these variables are treated as endogenous variables (See Table 10).

Table 10
Estimated Determinants of Two Major Groups of Research and Extension Spending*

Independent Variables	Dependent Variable: Field Crop Research Spending (1)	Field Crop Research Spending (2)	Horticultural Crop & Livestock Research Spending (3)	Horticultural Crop & Livestock Research Spending (4)	National Extension Spending (5)	National Extension Spending (6)
Intercept	2.69 (2.48)	2.36 (2.27)	3.08 (1.94)	3.37 (2.16)	43.01 (1.56)	75.72 (3.18)
PROD	.001 (2.98)	.001 (3.91	.005 (5.92)	.005 (5.65)	- -	- -
PROD2	$-1-2x10^{-7}$ (3.98)	$-1.2x10^{-7}$ (4.16)	$-1x10^{-6}$ (5.58)	$-1x10^{-6}$ (5.58)	- -	-
TOTLAREA	- -	- -	- -	- -	.005 (4.79)	.003 (4.21)
DIVER	1.09 (1.54)	.055 (.14)	.287 (.27)	1.17 (2.08)	9.15 (.28)	8.89 (1.11)
PRDIVER	.001 (1.17)	.0005 (.63)	-.005 (3.03)	-.004 (2.61)	- -	- -
AREADIV	- -	- -	- -	- -	-.014 (3.88)	-.007 (2.93)
UREARICE	.044 (.81)	.033 (.06)	-.125 (1.62)	-.088 (1.29)	-5.82 (2.16)	-5.16 (5.51)
ARABLE	.574 (1.03)	.493 (.91)	-1.20 (1.48)	-1.11 (1.38)	-2.51 (.17)	-19.88 (1.57)
ECONAG	-.060 (3.35)	-.039 (3.27)	-.015 (.58)	-.034 (1.91)	.223 (.23)	-.297 (1.09)
URBANPOP	-.035 (2.91)	-.023 (2.40)	-.013 (.75)	-.022 (1.50)	-.113 (.24)	-.309 (1.45)
EXPRAT	-.008 (1.05)	-.011 (1.45)	.054 (5.17)	.053 (4.83)	-1.87 (7.31)	-1.67 (7.85)
INTLOC	-.285 (.57)	-.095 (.19)	1.27 (.99)	.975 (.79)	- -	- -
INTSPLOC	.211 (1.12)	.185 (1.00)	.378 (.70)	.342 (.63)	- -	- -
PRDXPORT	$2x10^{-6}$ (5.71)	$2x10^{-6}$ (5.50)	$1x10^{-5}$ (10.85)	$1x10^{-5}$ (10.86	$3x10^{-5}$ (3.59)	$2.5x10^{-5}$ (3.35)
PRDMPORT	$1.7x10^{-6}$ (9.43)	$1.6x10^{-6}$ (9.53)	$7x10^{-5}$ (5.01)	$7x10^{-5}$ (5.04)	$-3x10^{-6}$ (.90)	$-3x10^{-6}$ (1.00)
RESNSR	.031 (3.35)	.024 (2.95)	.019 (2.38)	.023 (3.17)	-.179 (.58)	-.277 (1.66)
T1	.126 (1.03)	.048 (.42)	.239 (1.29)	.283 (1.57)	-9.19 (2.75)	2.87 (.66)
R1	-.451 (1.59)	-.156 (.55)	-.786 (1.88)	-.951 (2.32)	-3.42 (.38)	-4.23 (.76)
R2	.409 (1.26)	.204 (.70)	-.111 (.24)	.123 (.29)	25.02 (2.05)	34.59 (5.65)
CINTSP	-.002 (.42)	$2x10^{-5}$ (.00)	.026 (3.00)	.025 (2.90)	.018 (.14)	.086 (.93)
B001.AID	.027 (2.04)	- -	-.020 (1.02)	- -	.012 .01	- -
B001.WBRES	-	.006 (1.38)	- -	-.001 (.20)	- -	- -
B001.WBEXT	- -	- -	- -	- -	- -	.367 (3.30)
AREACINT	$1x10^{-6}$ (4.29)	$1x10^{-6}$ (4.07)	$1.6x10^{-6}$ (6.15)	$1.6x10^{-6}$ (6.05)	$3.7x10^{-6}$ (1.04)	$2.5x10^{-7}$ (.08)
R^2F	43.17	45.03	32.16	32.36	35.31	47.25
R^2	.64	.65	.59	.60	.55	.62

*Absolute values of asymptotic t-ratios in parentheses.

diversity. They provide more aid to large countries with little diversity. Countries with small areas and high levels of diversity are in some sense discriminated against by donors. This is in contrast to a result in Table 10 showing that national governments do not respond negatively to diversity in their own funding decisions. Interestingly the IARCs do respond positively to diversity in their non-host staffing decisions.

It appears that when governments pursue high fertilizer/rice price policies (interpreted here as general policies discriminating against farmers and in favor of consumers) aid agencies respond by offering less aid to research (and possibly more to extension). They do not compensate for anti-supply policies by investing more in research. Their research programs are also more basic and more congruent. That is they are less commodity oriented and better matched to their commodity production patterns.

Aid donors generally tend to respond to land exhaustion (i.e., low levels of the ARABLE variables) by offering more aid to research. The World Bank does not. Aid donors including the World Bank do appear to respond positively to the importance of the agricultural work force in the general labor force. This is in contrast to the tendency of national programs to spend less when the proportion of workers in agriculture is high. This is perhaps the one dimension where aid donors appear to be inducing more "qualitatively optimal" programs.

Aid donors do not appear to respond to IARC locations in their programming. The IARCs, however, do favor IARC host countries in their placement of non-host staff and research contracts and collaborative agreements -- that is, centers tend to outpost staff and conclude agreements in countries where other centers are located.

The qualitative dimensions of national programs appear to respond to political factors to some extent. A higher proportion of the labor force in agriculture appears to induce more commodity oriented and more congruent research programs. National programs also appear to respond to strong research programs by geo-climate neighbors by undertaking a lower proportion of non-commodity research.

Research and Extension Determinants -- Two Period Data

Table 10 reports the most important results of this analysis. It shows the determinants of national research spending on field crops research, on livestock and horticultural crops research and on extension spending. Two versions of each equation are reported. In the first (eg. 1, 3 and 5) general aid is treated as a determinant of spending. In the second (eg. 2, 4 and 6) World Bank aid to research (or extension) is treated as the determining variable. Cumulated IARC spending (CINTSP) on the commodity is treated as an exogenous variable[9/] and tests whether IARC programs have stimulated or retarded national spending. This variable is also interacted with a variable measuring the size of the crop area in the country (AREACINT = TOTALAREA x CINTSP). This is designed to measure whether the IARC impact is related to the size of the country.[10/]

Table 10 shows that IARC spending did not affect extension spending, but that it clearly did have a positive impact on both field crop research spending and on livestock and horticultural crop research spending. Further, the impact is positively related to the size of the country being affected. For field crop research the approximately zero coefficient on CINTSP shows that for small countries there is little or no IARC impact. For small countries the AREACINT variables has a low value. For large countries the positive impact is substantial. For livestock and horticultural crops it appears that a positive impact holds even for small countries. These results are not affected by the choice of aid variable.

The response of national research system spending to IARC spending is consistent with the estimated positive response to research undertaken by geo-climate neighbors. The RESNSR variable measures the scientist years devoted to the commodity by other countries in the same broad geo-climate zone. The positive response to this research and to IARC research shows that national systems see this research as opening up adaptive opportunities for their own research investment. The fact that countries do not respond to this research spending by spending more on extension is also consistent with a perception that the new technology being produced in these systems is not so well matched to their own production environments that they can simply facilitate its "spill-in" and adoption by investing in extension.

Thus the pattern of response in both research and extension spending to both IARC research and the research of geo-climate neighbors is consistent with the fact that agricultural technology has a high degree of location specifity. The typical developing country appears to have recognized that new technology does not easily spill-in from abroad and that low cost extension investment is not sufficient to facilitate its transfer. On the whole, technology produced abroad is mismatched to conditions at home. The degree of the mismatch is not so great, however, that it does not present new opportunities for adaptive research at home. In addition to mismatched technology, research institutions abroad are also producing pre-technology science of relevance. It too, is of value at home only when a strong research capacity has been built.

This interpretation of the IARC impact has important policy implications (as described below). The statistical measures reported in Table 10 support this interpretation. However, it is also important that the more general investment estimates be judged against *a priori* logic or expectations to determine whether the specific IARC impacts are part of a generally consistent investment relationship.

To this end, consider the impacts of the economic variables on investment. For all research activities, the PROD and PROD2 impacts are significant and as expected. Holding geo-climate diversity constant, an increase in the units produced of a commodity offers a type of scale economy to a research system. Thus spending per unit of production will decline as shown by the negative production squared term.

An increase in diversity itself does not have a strong impact on field crops research, (although it is positive), but does appear to stimulate more spending on livestock and horticultural research when production is low. High levels of diversity reduce the production input on this research spending. The same situation holds for extension spending. Higher levels of diversity lower the impact of total area on extension spending. This appears to be a kind of diseconomy or discouragement effect.

The expected negative sign on the ARABLE variable is borne out only for the livestock and horticultural crops research (and possibly for extension). When the ratio of arable land currently to arable land six years previously is low it is indicating an exhaustion of arable land.

The EXPRAT variable measures the ratio of a "price" of research services to a price of extension services. Since the dependent variable is expressed in expenditure terms if this variable has a zero coefficient, the actual price elasticity is -1[11]. Since this ratio is probably measured with error its coefficient will be biased toward zero. It is important, therefore, that the standard error be considered in interpreting this variable. To facilitate this a range of price elasticities (+/-1 standard deviation) is reported in the following section. This range shows that prices do matter. Those countries that have lowered this ratio by developing a capacity for training scientists at home and a reduced dependency on costly expatriate scientists have responded by buying more units of research and by spending more on research.

The variables measuring political factors are important. They show very strong international trade effects. If a commodity is exported more research per dollar of product is expended for all commodities. Export orientation also stimulate extension spending. This impact is higher for the horticultural crops and livestock, perhaps reflecting post-colonial effects in which research or export commodities traditionally had strong "mother country" support. It is interesting, however, that the impact of imports of the commodities has a stimulus effect of roughly the same magnitude in field crops and of larger magnitude for the livestock and horticultural crops. Imports do not affect extension spending.

This extra attention to traded commodities has several rational explanations. Most developing countries have pursued general economic policies that place a high value on foreign exchange. Demand elasticities for traded crops are high so supply can be increased without significant reduction in market prices. Increased imports of commodities may also provide political signals that something should be done about domestic supply. Of course, there still may be a colonial legacy reflected in the data but the import effects suggest that a more general set of factors are operating to favor traded over nontraded commodities.

The variable proxying for agricultural price policies, UREARICE, does not have significant effects on research although countries pursuing price policies that discriminate against farmers (as measured by a high urea-rice price ratio) tend to spend less on livestock and horticultural crop research. They also spend less on extension thus they do not attempt to compensate for negative price effects on supply by spending more on research and extension.

The variable measuring the characteristics of the agricultural labor force and the urbanization of the population reflect very good political processes and cannot be given very clear interpretations. An increase in the percent of the population living in urban centers of 100,000 population and more tends to reduce spending on research and extension, particularly on field crops research. This presumably is measuring political power with an interest in directing government spending to nonagricultural interests. Countries with high proportions of their labor force in agriculture also spend less on research and extension, particularly field crop research. This variable is not measuring the same phenomena as the urbanization variable, but it is not inconsistent to suggest that farmer political power is actually weakest in the poorest economies with high proportion of workers in agriculture. Since this variable is also a proxy for the general wealth of a society it may be measuring a kind of wealth effect. If so it should be noted that there is a certain irrationality behind it since investment in research and extension is a production investment, not a form of public consumption.

The results reported in Tables 9 and 10 are based on the two period data set for which aid variables are available. The results with respect to the aid variables show that general aid for research (as measured by AID) does increase research spending for field crops research but not for livestock and horticultural crop research or for extension. The coefficients show displacement of aid effects on research spending of two sorts. First, research spending on field crops does not increase by the full amount of the aid. Second some reduction in livestock and horticultural crop research is induced by aid.

The results when World Bank aid is provided are similar for aid to research although the apparent displacement is more severe. World Bank aid to extension, on the other hand, provides a strong stimulus to national extension investment.[12/]

The magnitude of the aid and other impacts on spending will be discussed further in the concluding policy section of the paper. Before turning to that discussion, results from the second data set are reported.

Annual Data Analysis

The annual data set, as noted earlier, does not have data on aid variables. It is however, considerably richer in terms of observations by commodity. Accordingly the results reported in Table 11 are by commodity and for pooled commodity groups: cereals (maize, sorghum, millet, rice, wheat), staples (beans, cassava, groundnuts, potatoes, sweet potatoes) and commercial crops (soybeans and sugar). (Dummy variables for commodities are included in all pooled regressions). The specification differs from that in Table 10 in three ways. First, since aid variables are not available, the variable VIOLD, (a predicting variable in the earlier analysis) is included in these regressions. Second, an effort is made to estimate both an area and production and hence yield impact on research spending. Third, international trade variables were not included in these regressions.

These results are generally consistent with those reported in Table 10 and show a high degree of consistency across commodities. The IARC spending impact which is of central concern to this study has a statistically significant coefficient in regressions for maize, sorghum, rice, wheat, potatoes and sweet potatoes and in the pooled cereals and staples regression. Other studies have shown that the IARC contributions in terms of technology development and research contributions have been higher in these commodities than in beans, cassava and groundnuts. These latter commodities are generally regarded to

Table 11: Estimated Determinants of Commodity-Specific National Agricultural Research and Extension Spending
Annual Data 1963-80 - 25 Countries

Dependent Variable: Spending in 1980 Dollars

Independent Variables	Maize	Sorghum	Millet	Rice	Wheat	Cereals	Beans	Cassava
PRODUCTION	0.000024*	0.00013**	0.00074**	0.00041**	0.00047**	0.00023**	-0.00168**	0.000024**
AREA	0.000045*	-0.000013	-0.00033**	-0.00056**	-0.00031**	-0.00019**	0.00135**	-0.00008**
IARCSPENDING	0.000009**	0.000022*	0.000040	0.0000067*	0.000069**	0.000016**	0.0000065	-9.517E-07
UREARICEPRICE	-0.0302	-0.0503**	-0.0387*	-0.0259	0.2594**	-0.0971**	-0.0188	-0.0452**
RESNEIGHBORS	0.0217**	0.0307**	0.0355**	0.0121**	-0.0556**	0.0129**	0.0434**	0.0672**
PROPAGRWKRS	-0.0132**	-0.0124**	-0.0177**	-0.0599**	-0.0079	-0.0286**	-0.0059*	-0.0035**
URBANIZATION	-0.0049	-0.0064*	-0.0078*	-0.0539**	0.0241**	-0.0266**	-0.00049	-0.00092
RESEXTPRICE	0.0076*	-0.0109**	-0.0094*	0.0361**	0.0702**	0.0173**	-0.0236**	0.0016
LAND EXHAUSTION	-0.3481	-0.0993	-0.2721	0.0174	0.5191	-0.1608	-0.3485	-0.7014**
DIVERSITY	0.6024**	0.4825**	0.7590**	1.0257**	-0.2170	0.3572	0.4242**	-0.063[illegible]
PROD X DIVERSITY	0.000015**	0.000019**	0.000022**	0.000038**	0.000054**	0.000017**	0.000016**	-0.0000013*
POLVIOLENCE	-696.59**	-555.88**	-616.31**	-2016.22*	-3383.09**	-649.20**	-548.93**	-113.82
R^2	0.5554	0.5904	0.6905	0.7575	0.8179	0.6859	0.7526	0.2946
F	48.94	56.46	61.12	122.32	175.95	173.45	119.15	16.36

Independent Variables	Groundnuts	Potatoes	Sweet Potatoes	Staples	Soybeans	Sugar	Commercial Crops
PRODUCTION	0.00014**	-0.00007**	0.0000012	-0.000028**	0.000082	0.000043**	-0.000014**
AREA	-0.000031	0.0033**	0.00011	0.00023**	0.0011**	-0.0018**	0.0014**
IARCSPENDING	0.000026	0.0000042**	0.000019**	0.000006**	n.a.	n.a.	n.a.
UREARICEPRICE	-0.0144	0.0238**	-0.0426**	-0.0240**	-0.0206	0.0556**	0.0231*
RESNEIGHBORS	0.0358**	-0.0069	-0.0637**	0.0399**	0.0218**	0.0118*	0.0182**
PROPAGRWKRS	-0.0052**	-0.0122**	-0.0030*	-0.0048**	-0.0107**	-0.0250**	-0.0185**
URBANIZATION	-0.0021	-0.0054**	-0.0052**	-0.0015	-0.0081*	-0.0047	-0.0060**
RESEXTPRICE	0.0052*	-0.0060**	0.0019	-0.0066**	-0.0179**	0.0023	-0.0088**
LAND EXHAUSTION	0.0086	0.2074	-0.1212	-0.0386	0.6474	0.0393	0.3016
DIVERSITY	0.4257**	-0.3061**	0.0131	0.0855	0.4924**	1.0267**	0.7411**
PROD X DIVERSITY	0.0000057**	-0.000004**	2.967E-07	0.0000059**	0.000021**	0.000023**	0.000021**
POLVIOLENCE	-181.44*	72.86	-39.83	-250.59**	-1378.33**	-547.79**	-969.57**
R^2	0.4169	0.6297	0.1432	0.3297	0.8886	0.7037	0.8203
F	28.00	66.61	6.55	98.45	341.67	101.67	396.02

*T ratio between 1.5 and 2.0
**T ratio greater than 2.0

present "difficult" challenges to researchers. To some extent this is due to the fact that they have received research attention for a shorter period of time then is the case for the cereal grains, where considerable research in developed countries has been undertaken over many years.

The response to the research by geo-climate neighbors is positive in most commodities and in the pooled regression confirming the results reported in Table 10.

An increase in production holding area constant, i.e., an increase in yields, stimulates research spending in the cereal grains and cassava, but yield is not generally highly correlated with research spending. An increase in general diversity does stimulate more research spending in almost all commodities and the production impact on research spending is higher for all commodities, the higher is the level of diversity.

These data show relatively weak land exhaustion effects. The relative price of research to extension services is a significant determinant of spending. It shows some bias in that a decline in the costs of doing research seems to stimulate research spending on wheat, rice and maize most.

Land exhaustion effects are generally not significant. The political variables ECONAG and URBANPOP show effects similar to those reported for Table 10. Urbanization appears to be biased toward stimulating more wheat research and less research on other commodities. When the price policies of countries discriminate against farmers, they also discriminate against research spending except for wheat and potatoes. Political violence is associated with reduced spending for most types of research.

On the whole, the results for specific field crop commodities reinforce the conclusions of the earlier analysis. They show a high level of consistency across commodities.

IV. Policy Implications of Investment Analysis

The results of the econometric exercise reported in Tables 9, 10 and 11 have substantial policy relevance. While they do show a considerable degree of consistency with rational planning on the part of national governments it cannot be concluded that there is little reason for active policy interventions to change national government investment. Indeed another large body of evidence (see Evenson, Waggoner and Ruttan 1981 and Ruttan 1984) shows that research investments have produced extraordinarily high returns in terms of the increased agricultural output associated with research programs. The implications is that there is general underinvestment in research. Comparisons by region and by commodity show substantial variations implying underinvestment in at least some programs of research.

With this in mind then it is useful to calculate the marginal impacts of alternative policy-related activities on national research and extension spending. table 12 reports a number of such calculations based on the regression estimates reported in Tables 10 and 11.

The table shows that the elasticities of both research and extension spending with respect to production evaluated at the mean are in the .55 or .6 range. This means that at the mean of the sample a ten percent increase in production induces a 5.5 to 6 percent increase in spending. This could be due to fixed costs of undertaking research and extension programs and "real" scale economies to size. The implied scale parameter is essentially the inverse of this elasticity (i.e., 1/.6 = 1.66). However, it may reflect an overestimate of real scale economies and a tenancy on the part of governments to feel that once a substantial research program is in place, it need not be expanded with the importance of the crop. Conversely it may reflect a tendency to build research programs for minor commodities.

Table 12: Calculated Impacts on National Research and Extension Investment (Millions of 1980 Dollars)

Policy Variable	Annual Research Spending Million Dollars (from Table 10): Field Crops	Livestock and Horticulture Crops	Extension Spending
1 million $ added to (elasticity)	.551	.584	.592
Commodity production (dollars)	.00164	.00396	.00624
1 million $ added to commodity exports	.000634	.002277	.00695
1 million $ added to commodity imports	.000472	.01253	-.000937
1 added SY by geo-climate neighbor	.0305	.01901	-.1792
Ten percent decline in research costs per SY on ten percent spending ± std. derviation	.00005	-.00064	.00188
rice is extension costs EW	-.00017	-.00042	.00145
quantity elasticity ± std. derviation	-1.051	-.474	-1.456
	-1.191	-.652	-1.591
1 million dollars added to IARC research stock			
a) first year	.229	1.084	.105
b) after 10 years	2.290	10.840	1.050
1 million dollars general aid research	1.194	-.858	+.047
World Bank aid (to research or extension)	.285	-.063	1.468

	Research Spending by Commodity (from Table 11): Maize	Sorghum	Millets	Rice	Wheat	Beans	Cassava	Ground nuts	Potatoes	Sweet Potatoes
1 added SY by geo-climate neighbor	.0217	.0307	.0355	.0121	-.0506	.0434	.0672	.0358	-.0069	-.0637
Ten percent decline in urea-rice price	.030	.050	.039	.026	-.259	.019	.045	.015	-.024	.043
1 million dollars added to IARC investment										
a) first year	.225	.550	1.000	.168	1.725	.162	-.000	.650	1.050	.475
b) after 10 years	2.250	5.500	10.00	1.680	17.250	1.620	-.000	6.500	10.500	4.750

The table also shows that when the commodity being produced is exported research spending per unit of product is 1.39 as high for field crops and 1.54 times as high as for livestock and horticultural crops as it is for non-traded commodities. When the commodity is imported, spending per unit of product is 1.29 times as high for field crops and over 4 times as high for livestock and horticultural crops (where imports are generally very low). The policy implication for these calculations is not that traded commodities receive too much research attention but that non-traded commodities almost certainly receive too little attention.

The positive response by countries to an added SY on the commodity by a geo-climate neighbor is quantitatively significant in field crops and appears to be biased towards all cereals except wheat but toward beans, cassava and groundnuts. The induced spending of $30,000 is large in view of the fact that the cost of the added SY may be only a little more than that.

The computations for a ten percent decline in the research costs per SY has policy relevance. Many countries have options to reduce these costs through improvement of their own capacity to train scientists and through better incentive structures to hold scientists in research positions. In Africa an expansion in the indigenous scientists component and a reduction in administrative costs can easily allow a reduction in costs per scientist.

Table 12 reports four computations associated with a ten percent decrease in research costs per SY. The upper two are the +/- one standard deviation <u>range</u> in expenditure change. The lower two are the +/- are standard deviation <u>range</u> in the elasticity of quantity with respect to the research (or extension) price. A decline in the research price by 10 percent will result in an increase in the quantity of SY's purchased of 10.5 to 11.9 percent for field crop research and 4.74 to 6.52 percent for livestock and horticultural crop research. This will mean a small increase in spending on field crops research and a decrease in spending on horticultural crop and livestock research. A ten percent decline in extension costs, on the other hand, will increase the purchase of extension workers by 14.5 to 15.9 percent and will also increase total spending.

The final calculations regarding aid and IARC spending are of most interest. The form of the model measuring IARC impacts was that the stock (i.e., cumulated expenditures in 1980 dollars) of IARC investment impacted on the annual flow of national research spending. Thus, a million dollar increment to IARC spending in 1978 would raise the value of the CINTSP variable in 1978, 1979, etc. If this IARC spending was in the field crops it would stimulate $229,000 added annual national research investment in the first year (1978). (This is calculated as the total of the spending impacts in the 24 countries in the sample. Presumably the scope of influence is wider than for these 24 countries, so this is an underestimate of the effect). By 1988 a total of $2,290,000 added annual national research investment would have been stimulated by the 1 million dollar expenditure in 1978. When the data at hand it is not really possible to estimate the deterioration of this effect. It is conservative to suppose that it will last only ten years (about the average time period for IARC investment in the data set).

The results for individual field crops (based on Table 11 and the annual data) also show investment impacts that are generally large. Only cassava shows no impact. IARC investments of one million dollars in potatoes, sweet potatoes, wheat, sorghum and millets appear to stimulate an added million dollars in national spending within one or two years. Even for maize and rice the added national investment is significant.

This may be compared with the estimates for direct aid. They show that 1 million dollars in general aid increases field crop research by more than 1 million dollars but at the cost of reduced spending on livestock and field crop research. Thus taking this displacement into account, only $336,000 net incremental research spending takes place for the one million dollar aid grant or loan. The same calculation made for World Bank aid shows an even more severe displacement effect. A million dollars in World Bank aid results in only a net increment to spending of $222,000. In rather sharp contrast, it appears the World Bank extension aid has a large stimulus effect on extension spending.12/

The aid inputs, it must be noted, are difficult to estimate and this will lead some policy makers to discount them. Most aid donors, however, are predisposed to believe that their aid has sufficient "strings" that it will not be displaced. Yet, most of it, in fact, is displaced and generally displacement is probably efficient. When accompanied by strong policy advise and pressure as in the case of World Bank extension aid (the T. β V. system) aid can have a large effect.

It appears then that the IARC system has had a significant and positive impact on national research (and extension) programs in the developing world. It has stimulated more spending in national systems and this impact is sufficiently large that an aid donor interested in stimulating national research spending actually received more stimulus from a grant to the iARC system than from a direct grant to a national system. The IARC system has probably also had a significant impact on more qualitative aspects of national research systems as well.

V. Impact of Investment on Productivity

A large number of studies showing relationships between agricultural productivity changes and investment in agricultural research programs in specific countries have now been undertaken. (Norton and Davis, 1981, and Ruttan 1984 provide reviews). However, in spite of the voluminous literature on the "green revolution", part of which was associated with International Agricultural Research Center (IARC) investments, little systematic study of IARC impact on productivity has been made. This is in part because the impact of an IARC is international in character. Some studies of productivity in a particular country (Evenson, 1983 for India) have inferred IARC impact on the basis of IARC-based high yielding variety (HYV) data. This, however, does not capture the full IARC impact because much of it is channeled through avenues other than HYVs and because it occurs in a number of countries. This section reports econometric estimates of impacts on crop productivity of national investment in crop-specific research, IARC research on the commodity, and national investment in extension.

Specification of the Productivity Relationship

Since the focus of this section is on IARC effects, certain data limitations will have to be accepted. It will be necessary to pool data from several countries. Further, it will be necessary to deal with commodity-specific data since the interest is in particular IARC programs rather than in their general or average impact. This means that the only real crop-specific productivity variables which can be observed are measures of production and area harvested. In addition it is possible to measure irrigated area of all crops relative to all harvested area and fertilizer used.

It is not really possible then to estimate a full production function or to compute a total factor productivity index by crop for each country. The practical alternative options are to estimate one of the following specifications:

(1) $PROD/HA = a+bHA+cI^*+dF^*+eR$

(2) $LN(PROD) = a'+b'LN(HA)+c'LN(I^*)+d'LN(F^*)+e'R$

where PROD is production in metric tons.

HA is hectares harvested.

I* is the ratio of irrigated area to planted area for crops that are normally irrigated.

F* is the ratio of fertilizer used (valued at constant world prices) to acreage of crops normally fertilized.

R is a vector of research-extension variables.

These specifications are production function "proxies". The variable, HA, actually has 3 roles in the specifications:

a) It measures productive services from land

b) It measures land expansion - contraction effects (i.e., where land quality for new plantings may differ from the average land quality for the commodity)

c) It is correlated with other "left out" inputs such as labor and machine services and it may thus "pick-up" their effects.

This study is not directly interested in the estimates of a', b', c', or d'(or a, b, c, and d) per se. Nor is the exact functional form of the production function an important issue since no attempt will be made to interpret coefficients as technical substitution parameters. The data available are not suited to addressing these relatively fine questions.13/ The primary concern is with estimates of the e' vector of coefficients on the research-extension variables.

Option (2) above is chosen as the more reasonable specification because left-out unmeasured inputs are likely to be proportional to cropped area (Ha). The coefficient b' would, of course, not be an estimate of the marginal product of land in that case, but as noted, that is not of direct concern. The log-linear relationship between the research-extension variables and production is also consistent with some evidence of research productivity. Griliches (1958) found that hybrid corn varieties tended to improve yields proportionately rather than additively. The I* and F* variables are included only for those crops that are either irrigated or fertilized. These variables are not measured on a crop-specific basis, but they are likely to be proportional to actual crop-specific variables and hence their inclusion can reduce bias.

All specifications include country dummy variables. Thus "country effects" such as soil and climate factors, measurement errors, infrastructure, etc., that affect production or yield levels, but not their change over time, are picked up by these dummy variables. Specifications that pool commodities also include commodity dummy variables.

Simultaneity problems may exist if national research and extension program investment responds to both production and area (i.e., to yield). a number of studies have dealt with this by simply arguing that the relationship is "recursive". That is, current research investment may respond to current yield performance, but current yields are responding to past research investments. In this study, the problem will be dealt with formally by utilizing the two stage least squares' estimates from Table 11 to construct the research variable.

The actual variables specified for this study are defined as follows:

$$(3) \quad PRESI_t = .2R^*_{5-1} + .4R^*_{t-2} + .6R^*_{t-3} + .8R^*_{t-4} + \sum_{i=5}^{1959} R^*$$

where R^*_t is predicted research spending in time t. The prediction is based on the investment analysis reported in Table 11.[13/] The weights used were indirectly estimated by constructing an alternative stock using weights rising to one by year t + 9. This stock was slightly inferior to the specified stock.

$$EXTDIV = (.5Ext^*_t + .25Ext_{t-1} + .25Ext_{t-2})DIVER$$

where EXT_t is actual spending in 1980 dollars on all agricultural extension.

$DIVER = \sum S_i^2$ where S_i is the share of total production of a specific commodity in a specific geo-climate region. Livestock commodities are included in the construction of DIVER. Note that the weights for EXTDIV sum to one implying that no long-term impact from extension is realized. The full impact is realized by the end of year t + 2.

$$(4) \quad INTR_t = .2IARC_{t-1} + .4IARC_{t-2} + .6IARC_{t-3} + .8IARC_{t-4} + \sum_{i=5}^{1959} IARC_{t-i}$$

Where $IARC_t$ is spending by the IARC in 1980 dollars in time t.

The following "interaction" variables were defined:

EXTDJV = EXTDIV*PRESI
INTRPRES = INTR*PRESI
INTREXT = INTR*EXTDIV

One further modification was made to take into account the fact that IARC impacts are not likely to be the same in all countries in the data set. It would be, as a practical matter, nearly impossible for IARC programs to produce the same production impact in each of the 24 countries in the data set. The IARC will in most cases be producing technology that is more closely matched to producing environments similar to its host country than to environments that are dissimilar. This should not only affect the productivity impact of the

IARC program but its interaction with national research and extension programs as well.

To attempt to take this into account, a variable, SR, is defined. This variable is equal to the proportion of the area planted to the commodity in the country of observation that is located in the same geo-climate region as the IARCs central location. The geo-climate regions are defined by Papadakis (1965) and have been used in other studies of international productivity impact. (Evenson 1979, Evenson 1983). The following variables were then defined:

INTRSR = INTR*SR
INTRESSR = INTRPRES*SR
INTREXSR = INTREXT*SR

The coefficients of these variables measure added impacts in similar geo-climate regions. The reasoning offered above would lead to the expectation that direct IARC impact via the provision of matched technology will be higher in similar regions, while the indirect impact via the provision of mismatched technology could be larger outside the similar region. It is possible, of course, that both effects will be larger in similar regions.

Productivity Impact Estimates

The econometric analysis proceeded in three stages. In the first stage the predicting equations required for building the research stock variables were estimated (discussed in Part III above). In the second, crop productivity specifications were estimated for each of the 10 commodities in the study using data for all 24 countries. In the third stage, regional estimates for Asia, Africa and Latin America were obtained for maize, millets and sorghum pooled, all cereals pooled and all staple crops pooled.

The results for stage 2 are summarized in Table 13.

Table 13 reports the coefficients of the interaction terms in the model and

Table 13: Estimated Crop Production Elasticities (Computed at the Mean) by Commodity 24 Countries, 1962-80. (See Appendix 2 for Actual Estimates).

	Interaction Effects					Production Elasticities					
		IARC Res X NRES		IARC X NEXT		National Res		National Ext		IARC Res	
COMMENTS	NRES X NEXT	Added GCSR	General	Added GCSR	General	Added GCSR	General	Added GCSR	General	Added GCSR	General
Maize	-.448(3)*	-.222(5)*	-.139(6)	.596(5)	-.743(7)	-.0234*	.0733*	.432	.018	.136	.340**
Millets	.440(3)**	-.197(3)	-.154(4)*	.349(5)	-.139(2)	-.065	-.019*	-.067	.006	.728	.000
Sorghum	-.251(2)**	-.252(4)*	.368(5)**	-.167(3)*	.212(5)	-.096*	.068**	-1.41	.188**	2.75**	-.019*
Maize, Sorghum, Millets	-.109(2)**	-.228(5)	.416(6)**	.428(5)**	-.139(6)	.079	.120**	.197**	.082**	.240*	.029**
Rice	-.336(3)**	-.433(6)**	.349(8)	-.205(5)**	.219(6)**	-.102**	.075**	-.361**	.091**	.821	-.002
Wheat	-.395(4)	.379(6)*	-.336(6)**	-.986(5)**	-.472(6)**	.336*	.271**	-.622**	.004	-.025	.044**
Cereals	-.322(3)**	-.799(7)	-.159(7)	-.181(6)*	.718(8)	.050	.058**	.036*	.048**	.189**	.027**
Beans	.268(3)	-.362(5)**	.859(6)*	-.170(5)	.899(6)	-.064**	-.031*	-.246	-.008*	.030**	.056**
Cassava	.195(2)**	.548(5)	-.776(5)**	-.111(4)**	-.911(6)	.416	.419**	-.236**	-.059**	.099**	-.012
Groundnut	-.758(3)		-.823(5)		.582(5)*		.045*		-.062		.001*
Potatoes	-.805(3)	-.696(6)	-.167(5)**	.753(7)	-.632(7)	.141	.015**	.091	.067**	.054**	.031**
Sweet Potatoes	.947(2)**	-.123(3)	-.385(4)**	.774(5)	-.525(6)	-.001	.202	.232	.101*	-.35**	-.108**
Staples	.531(4)	-.418(4)**	.364(5)**	-.598(5)**	.111(5)**	-.034**	-.010	.008**	.097*	.073**	.095**

Notes: Number in parenthesis are E(-n)
* "t" or comparable "F" indicates significance at the 5 to 10 percent level.
** "t" or comparable "F" indicates significance at the 5 percent or lower level.

the computed partial production elasticities for each commodity. The full regressions are reported in Appendix 2. All commodity regressions are reported as are pooled regressions for maize, sorghum and millets, all cereals and all staples. The reader can readily see that the pooled regressions show more stable and consistent elasticity estimates. It is important to bear in mind that most studies of research productivity impacts are in fact based on aggregated or pooled data.

Consider first the interaction effects. The first column of Table 13 shows that national research and extension programs are substitutes in the cereals. IARC research is also a substitute for extension in rice and wheat in similar geo-climate regions. This means that spending more on extension lowers the marginal product of research and spending more on research lowers the marginal product of extension. For staples, it appears that national research complements extension in cassava and sweet potatoes where IARC research hasn't been effective. Where IARC research has been effective (as in cassava in similar regions) it tends to be a substitute for national extension.

It appears that with the exception of the maize-sorghum-millets combination, IARC research has either no significant interaction with extension or it has a negative substitution interaction. The story that IARC research enhances the productivity of national extension programs is not generally told by these data.

The interactions of IARC research with national research systems are also somewhat mixed. They are positive for sorghum, beans, and staples generally and negative for wheat, cassava, potatoes and sweet potatoes. The IARC effect in similar regions is negative for maize, sorghum, rice, beans and staples generally. It is positive only for wheat. This result is consistent with the arguments regarding the matching of technology. Technology from the IARCs should be more highly matched to a similar subregions and this should be manifested in lower IARC-NRES interactions in similar regions than in general. Wheat is the only case where the interaction is marginally significantly higher in similar regions. It has a strongly negative extension interaction, however, where the same argument can be applied. Note that, for extension, the IARC-NEXT interaction is generally lower in similar regions. Of the 24 IARC interaction coefficients in Table 13 for similar regions, 17 are negative, and 12 are significantly negative. Only one has a marginally significant positive coefficient. These results provide general support for the underlying logic of the specifications.

The production elasticities are "partial" elasticities. The elasticity for national research shows the percent change in production associated with a one percent change in the national research stock, holding national extension, IARC research and other variables in the equation constant. These elasticities are functions of the levels of other variables because of the interaction terms in the equations. They are evaluated at the mean of the data set. An "F" test is undertaken to test for the joint statistical significance of the coefficients entering the marginal product (and the computed elasticity). (See Appendix 2 for all coefficient estimates and F tests). The elasticities are computed for countries outside similar regions and the incremental elasticity for similar regions is also shown.[14/]

The IARC elasticities are computed on a presumption that IARC impacts will be realized in all 24 countries in the sample.[15/]

The elasticities bear a relationship to rates of return on investment. Suppose that a country is presently spending 1/2 of one percent of the value of product on cereals research. A one percent increase in research spending will raise this from .005V to .0050032V (i.e. .005x.01x15.5, where 15.5 is the ratio of the average stock to the average spending flow in the sample. A one percent increase in spending increases the stock by 1/15.5 percent. The elasticity estimate for cereals, .058, indicates that production will increase by .058 percent or .00058 times the value of production. thus an investment in time t of .0005V (V is value of the product), will generate an income stream that will be zero in time t, .2*x.00058V in t+1, .4*x.00058V in t+2, .6*x.00058V in t+3, .8*x.00058V in t+4, and .00058V in all years thereafter.[16] The discount rate which equates this earnings stream to the initial investment is approximately 35 percent. This is the internal rate of return to the research investment. Had the initial ratio of research spending been only .0025 instead of .005 the earnings stream associated with an elasticity of .058 would have yielded an internal rate of return slightly over 60 percent.

The ratios of research spending to the value of product for the 1972-9 period by commodity were: wheat .0051, rice .0025, maize-sorghum-millets .0023, cassava .0011, beans .0032, potatoes .0029, sweet potatoes .0007 and groundnuts .0025. Table 14 shows the conversion of elasticities for both research and extension to internal rates of return for different ratios of spending to value of product. The low income countries in the sample had a ratio of extension spending to value of product of .005. For the higher income countries it was .0075.

Table 14
Internal Rates of Return Corresponding to Given Research and Extension Elasticities at Selected Ratios of Spending to Productivity

Internal Rate of Return	Comparable Research Elasticity, Ratio of Spending to Productivity				Comparable Extension Elasticity Ratio of Spending to Productivity	
	.0003	.0025	.005	.01	.005	.0075
10%	.0006	.005	.010	.0200	.059	.088
20%	.0015	.0122	.0243	.0468	.068	.102
30%	.0025	.0212	.0421	.0841	.077	.116
40%	.0043	.0353	.0766	.1412	.087	.131
50%	.0051	.0416	.0851	.1702	.096	.145
60%	.0066	.0547	.1094	.2188	.106	.159
70%	.0081	.0675	.1350	.2700	.116	.174
80%	.0113	.0808	.1615	.3230	.126	.189
100%	.0131	.1088	.2175	.4350	.146	.219

With these conversions, the reader can see that national research investment has yielded generally high returns. National extension investment, as the table shows, must have an elasticity above .05 or .075 to yield a positive return, under an assumption that its impact does not last beyond 3 periods.[17] Extension impacts on cereal grain productivity and on potatoes and sweet potatoes productivity appear to be large enough to justify investment at the lower levels. Given the nature of the variable used, perhaps the most reasonable estimate is for the pooled cereal grains. This elasticity is sufficient to justify around one half of one percent on extension. Many countries, however, are currently spending roughly one percent of the value of product on extension. The estimate for cereal grains does not justify an investment of this magnitude.[18]

The estimates for both national research and extension should be interpreted with some caution. The productivity and effectiveness of both research and extension programs varies from country to country because of organization, leadership and general political and economic conditions. Studies in specific countries are required to investigate these issues further. The chief reason for resorting to international data in this study is that IARC impacts are international in character and cannot easily be measured in data for a single country.

The production elasticities for IARC investment for the pooled maize-millets-sorghum data and for pooled cereals show that IARC investment has an elasticity of .027 for the developing world in general and a considerably higher elasticity for countries in similar regions. This impact is essentially the "green revolution" impact. It implies a very high rate of return because the ratio of IARC spending to the value of the product is low, ranging from .0003 for the cereals to .0008 for potatoes. Thus an elasticity of .017 implies an internal rate of return of 100 percent. These high rates of return are, of course, based on the fact that the IARC impact occurs not just in one country but in the entire region. Because the spending to product ratios are low, these high returns imply that substantial growth in productivity is produced by the IARCs.

If IARC spending would have been 30% higher for cereal grains and had the same elasticities held, (a questionable assumption), production of cereal grains would have been (.027 x .2) = .0054 or one half percent higher per year (after the full impact is realized). This is a large growth increment from a relatively small investment.

The results for IARC investment in rice are a little puzzling as they show very high returns in similar regions and none outside these regions. It also appears that IARC investment in rice has sharply reduced the marginal products of national research and extension in similar regions. The definitions of regions for rice may be a little too broad to capture the same effects as for other commodities.

For the staple crops, it appears that there is an IARC impact in all commodities except sweet potatoes. For cassava, the impact is confined to similar regions. For beans and potatoes, the impact extends beyond similar regions. The returns to this IARC research appear to be as high as for IARC research in cereal grains. Given the very high leverage factor with IARC research almost any measurable impact (in a statistical sense) will tend to have a high rate of return.

The commodity-based results in Table 13 show that pooled commodity regressions tend to be more systematic than individual commodity regressions. Table 14 reports regional-based regressions for 3 pooled groups - maize-sorghum-millets, cereals and staples. All pooled regressions include commodity and country dummy variables. Appendix 3 reports the actual regression and F tests.

Table 15 does not include the similar region variables because the grouping of countries into the three broad regions achieves some of the same objectives. This table reveals patterns somewhat more clearly than did Table 2. The negative national research-extension interactions, for example, emerges for every region and every commodity group. The IARC - national research interaction is negative for cereal crops in Asia and Latin America, but is actually positive for staple crops in Latin America. The IARC-national extension extension interactions are generally positive, except in staple crops in Latin America.

The estimated productivity elasticities are also somewhat more regular. National research investments are highly productive, except in Africa for cereal grains (presumably rice and wheat) and Latin America for staples. Implied rates of return are high. They range from 30 to 40 percent for maize

Table 16: Regional Impact Analysis

Research-Extension Coefficient	Maize, Millets & Sorghum			Cereal Crops			Staple Crops		
	Latin America	Africa	Asia	Latin America	Africa	Asia	Latin America	Africa	Asia
PRESS1	.0121**	.0393**	.0314**	.0146**	.854(3)	.0106**	-.019**	.0733**	.0479**
EXTDIV	.0331**	-.609(4)	.0305**	.0158**	-.153(3)	.0389**	-.493(2)	.939(2)**	.0157*
EXTDPRES	-.117(2)**	-.939(3)**	-.172(2)**	-.364(3)**	-.228(3)	-.597(3)**	.318(3)**	-.101(2)*	-.457(2)**
INTRIARC	.286(5)	.809(5)	.213(6)	.560(5)**	.319(5)	.171(5)	.237(4)**	.371(5)	.514(5)
INTRPRES	-.179(6)	.445(6)	-.103(5)**	-.193(6)**	.157(7)	-.644(7)**	.685(6)*	-.228(5)	.105(5)
INTRXEXT	.129(5)**	.178(6)	.349(5)**	.501(7)	.222(6)**	.755(6)*	-.737(6)*	.653(6)	.188(5)
PRODUCTIVITY ELASTICITIES									
National Research	.0344	.0505**	.1168**	.1435**	-.0060	.1135**	-.0302**	.0313**	.1292**
National Extension	.1708*	-.0129	.1658**	.0745**	.0128	.1921**	-.0243** **	.1198**	.0685
IARC Research	.0317*	.0355**	.0416**	.0298**	.0543**	.0428**	.0412**	.0187	.0312*

Note: Numbers in parentheses are E(-n).

"T" or comparable "F" indicate significance at 5 to 10 percent levels.

"T" or comparable "F" indicate significance at 5 percent or lower level.

in Latin America and maize and staple crops in Africa to 60 to 70 percent for maize and cereals in Latin America, cereals in Asia and staple crops in Asia.

National investment in extension programs also generally appear to be productive, except in staples in Latin America and maize in Africa. The elasticities are high enough to justify a spending to value ratio of one half to one percent but not much higher.

IARC investment is productive across the board. The elasticities for cereal crops are highest in Africa and lowest in Latin America. The reverse is true for staples. The elasticities imply high internal rates of return to IARC investment, generally in excess of 100 percent everywhere.

As a region, Asia does best with high productivity elasticities for all three forms of investment for all commodities. Latin American has benefited from all investments except in staples. Africa has mixed results. IARC investment has been least productive in staples. National investment has been most productive in the staple crops.

VI. Policy Implications of Productivity Analysis

This paper shows, as do many others, that research directed toward the discovery and development of new agricultural technology has a high pay-off in terms of productivity growth. Not all research programs are successful, of course. In some cases, relatively new research programs may not be productive until a significant period of trial-and-error with scientific approaches and administrative and organizational change takes place. Most IARC programs are still quite young. Previous studies have documented high productivity of IARC research programs in wheat and rice, but relatively little systematic study of impact on other commodities has been undertaken.

The chief objective of this study was to use international crop productivity data to measure IARC impacts in ten commodities. Certain data limitations had to be accepted in doing so and this study is not a substitute for more detailed country studies. Nonetheless, the study did identify and measure significant IARC impacts as well as national research and extension impacts on crop productivity. In addition it identified several interaction and regional impacts of interest. (The study also attempted to deal with the simultaneous relationship between productivity and research and extension investment). The major findings were:

1) Measurable positive IARC impacts on crop productivity were observed for all commodities except sweet potatoes. For pooled commodity groups, grains, cereals and staples, positive IARC impacts were measured for all groups in all regions. Computed rates of return to IARC investment are very high.

2) IARC impacts are higher in countries in the same geo-climate region as the IARC central location. In most commodities these IARC impacts lower the marginal product of both national research and national extension programs. The IARCs produce technology that to some extent substitutes for the products of national research and extension.

3) Outside similar geo-climate regions, IARC impacts complement national research programs in some commodities, (maize, rice, beans) and substitute for others.

4) National research investment is highly productive in most commodities and in most regions. Internal rates of return to investment range from 30 to 70 percent for most commodities.

5) National research has a consistent negative interaction with national extension. Higher research spending reduces the impact of extension services. It appears that most extension services are not organized to directly channel or diffuse research products to farmers.

6) Extension services are also generally productive although their impacts

are much more variable. Rates of return calculations show that few programs have been productive enough to justify extension spending-to-product ratios above one percent.

The first part of this study examined the impact of IARC investment on national research investment. It concluded that IARC investment stimulated national research investment in most commodities, and concluded that the stimulus was probably because IARC research made national research more productive. The negative IARC-national research interaction terms for some commodities in this study raise some further questions on the issue.

It should be noted, however, that the negative interaction term is estimated at the margin and may not hold for the average relationship between IARC and national spending. Further, it may be noted that IARC impact can stimulate national research productivity by making longer-term contributions that are not necessarily picked up in these data. The IARCs do produce matched technology that will lower the productive impact of national programs. They also produce mis-matched technology and pre-technology science that has more general productivity enhancement effects. Finally, on this point, it may be noted that the strongest IARC stimulation impacts occur in wheat, potatoes, millets and groundnuts. These commodities also have the weakest negative IARC-national research interaction terms.

The policy questions to which these data speak are whether to expand the IARC system, whether to continue expansion and development of national research systems and whether to continue development of national extension programs.

The maintenance and expansion of the IARC system itself is determined by international entrepreneurs and by donor country attitudes. This is in contrast to national spending on research and extension which is subject to national economic and political forces. The signals from this study are quite clear and quite strong. Further investment in all IARCs is likely to be highly productive.19/ A donor agency interested in getting the maximum increment of food supply in the developing world from a given aid grant will obtain it by investing more in an IARC. This study shows that IARC impacts on crop productivity are probably higher than are national research program impacts. Furthermore, investment in IARCs stimulate more national system investment than will a comparable amount of direct aid.

These estimates of high productivity impact do not mean that all IARCs are optimally organized. What they do tell us is that the IARC concept is a good one. The IARCs have filled a vacuum, so to speak, and in their early years most have done so productively. The vacuum was the absence of strong science-based national research programs. It is now clear that national programs have made great progress, part of it due to IARCs. But a good deal more investment and institutional development is required before these systems will effectively substitute for the IARCs.

The signals from this study regarding national research system investment are also quite clear. In spite of variation in organization, skill levels and other characteristics, most national system programs are productive. Returns to investment are high. Most estimated elasticities are sufficiently high that they imply high returns to investment even if they are overestimated by a factor of 2 or 3. A blanket recommendation that all national systems should be expanded without regard to their existing organization and structure is not justified by these data. However, an expansion of well-organized systems is called for and the data clearly show the potential for high pay-off national system investments in all countries in the developing world.

Finally, the signals regarding extension investment, while generally positive, do call for caution. While it was assumed that extension does not produce a long-term income stream, it is, of course, possible that some permanent gains are due to extension. This possibility was not investigated in this study. There is a minimum productivity impact below which large investments in extension cannot justify extension spending to produce value ratios of much more than one percent of the value of agricultural product.

Perhaps the more serious issue regarding extension, however, is the lack of evidence that extension complements research. The strong negative interaction terms between research and extension suggests that extension productivity is based, not so much on extending research results but on more general productivity improving effects through improving farm management. There is noting wrong with this, but this finding suggests that more systematic study of the research-extension link is called for.

REFERENCES

Boyce, James K., and Robert E. Evenson. "National and International Agricultural Research and Extension Programs." Agricultural Development Council, 1975.

Commonwealth Agricultural Bureau. Abstracts-computarized data base.

Evenson, Robert E. "Observations on Brazilian Agricultural Research and Productivity." Revista De Economia Rural Vol. 20 No. 3, July/Sept. 1982.

Evenson, Robert E. "Economics of Agricultural Growth: The Case of Northern India".. In Issues in Third World Development. K. C. Nobe and R. K. Sampath (eds.), Westview Press, Boulder, Colorado, 1983.

Evenson, Robert E., P. Waggoner, and V. W. Ruttan. "Economic Benefits from Research: An Example from Agriculture." Science 205 (Sept. 1979).

Food and Agriculture Organization of the U. N. Yearbook of Production, annual.

Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovation." Journal of Political Economy 66 (1958):419-31.

Jamison, D. T., and L. J. Lau. "Farmer Education and Farm Efficiency." Baltimore, Johns Hopkins University Press, 1982.

Judd, M. Ann, James K. Boyce, and Robert E. Evenson. "Investing in Agricultural Supply." E.G.C. Discussion Paper 442, Yale University, Economic Growth Center, 1983.

Kislev, Yoav, and Robert E. Evenson. "Investment in Agricultural Research and Extension, An International Survey." Economic Development Cultural Change 23, April 1975.

Norton, G. R., and Jeffrey S. Davis. "Evaluating Returns to Research." American Journal of Agricultural Economics, Vol. 63 No. 4, Nov. 1981.

Dram, Peter, and Vishva Bindlish. "Resource Allocation to Agricultural Research: Trends in the 1970s (A Review of Third World Systems)." Washington, D.C., International Food Policy Research Institute, 1981.

Papadakis, J. Agricultural Climates of the World, Buenos Aires, 1965.

Ruttan, Vernon W. Agricultural Research Policy. Minneapolis, University of Minnesota Press, 1984.

World Bank, "World Development Report." Washington, D.C., 1983.

FOOTNOTES

[1]See Oram and Blindish, 1981 for a detailed discussion of expenditures in the international system.

[2]The development of national research and extension systems is documented in Judd, Boyce and Evenson, 1983, and Kislev and Evenson 1975.

[3]Judd, Boyce and Evenson, 1983 provide details. Appendix 1 to this paper provides country tables summarizing changes in national system development.

[4]The definition of country groups is that used by The World Bank in its World Development Report 1984.

[5]See Table 6 for a list of the countries; for the analysis, Taiwan is excluded.

[6]Diversity is measure at the country level. It is defined as

$$DIVER = \sum_{i=1}^{n} S_n^2$$

where S_i is the share in total agricultural product of the ith crop geo-climate combination.

[7]Many studies show that while consumers are the major gainers from agricultural research, they are not strong supporters of research (See Binswanger 198 , and Rose-Ackerman and Evenson 1985).

[8]The variable BASIC does not necessarily measure "basic" research. Non-commodity oriented research can include farming systems and economic research.

[9]The CINTSP variable is a naturally exogenous variable since IARC spending is undertaken in a specific location and thus cannot respond to country specific conditions. It can, of course, respond to commodity conditions.

[10]Note that this is not the area of the crop on which the research observation is made, but the area of all crops.

[11]Note that dC(PQ) = dP(O) + dQ(P)

$$\frac{d(PQ)}{dP} = Q + \frac{dQ}{dP}(P)$$

$$\frac{dPQ}{\alpha P} \cdot \frac{P}{PQ} = \frac{PQ}{PQ} + \frac{dQ}{\alpha} \cdot \frac{P}{Q} = 1 + \eta$$

[12]The World Bank is a relative late-comer to the research and extension support field. It provided very little support prior to 1974. Its lending since then for research and extension has been:

	Research	Extension
1974-6	227.5 $million	314.4 $million
1977-80	271.9 $million	1033.0 $million
1981-4	890.0 $million	740.5 $million

As can be seen, the Bank became a major factor in extension support after 1977 and a major factor in research after 1980.

[13]The weights in (3) were "estimated" by comparing the residual squared error of the equation with an alternative to (3) where the weights rose to one at 8 + 9 instead of 8 + 5. Specification (3) was slightly superior.

[14]These questions require farm level data from a reasonably homogeneous region.

[15]The elasticity for similar regions is the sum of the two elasticities.

[16]This is actually an underestimate of the elasticity since the coefficient estimates may apply to all developing countries, not just to the 24 countries in the sample. However, excluding the Peoples Republic of China, the 24 countries in the sample account for more than 85 percent of crop production in the developing world.

[17]Note that this presumes that spending occurs at the beginning of year t and productivity doesn't appear until the end of the year. Thus one full year is added to the implicit time lags built into the specification. A 6 months lag could have been used. This calculation is thus conservative.

[18]No attempt to test whether the impact lasts beyond three periods was made. however, had a different time configuration been built into the extension specification, its coefficient and its elasticity would have changed. The rate of return would probably not have changed very much.

[19]Caution in interpreting extension results from international data is warranted. Even if these estimates are unbiased, they represent an average impact from programs varying greatly in quality. Well-managed extension programs with skilled extension workers will have an impact higher than this average estimate indicates.

[20]This is the case even though the IARCs are relatively high cost institutions. Expenditures per scientist man-year are 2 to 3 times those of national systems because of international salary levels and more elaborate technical support. (See Judd, Boyce and Evenson 1983).

Appendix I

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in North America and Oceania (A Constructed Time Series, 1959 - 1980)

Country	Expenditures (000 Constant 1980 US$)								Scientist Years (Numbers)							
	1959	1962	1965	1968	1971	1974	1977	1980	1959	1962	1965	1968	1971	1974	1977	1980
Australia	76,169	95,918	156,421	169,591	281,760	267,447	286,823	306,199	1,500	1,700	1,900	2,130	3,000	3,200	2,425	2,59[illegible]
New Zealand	14,952	16,927	27,131	29,484	44,612	68,773	73,713	78,683	250	250	450	475	590	700	707	71[illegible]
Oceania 1/	91,577	113,408	186,553	200,071	328,004	337,901	362,339	386,806	1,759	1,960	2,362	2,618	3,608	3,919	3,132	3,30[illegible]
Canada	104,664	108,614	129,013	211,336	234,800	229,240	277,925	241,246	950	1,050	1,150	1,300	1,450	1,520	1,820	1,83[illegible]
United States	564,224	648,858	808,409	939,275	1,056,600	1,050,683	1,072,880	1,094,338	5,740	6,150	6,570	7,000	7,400	7,500	8,303	8,46[illegible]
North America	668,889	757,472	937,423	1,150,612	1,291,400	1,279,923	1,350,805	1,335,584	6,690	7,200	7,720	8,300	8,850	9,020	10,123	10,30[illegible]
Regional Total	760,466	870,880	1,120,976	1,350,652	1,619,404	1,617,824	1,713,144	1,722,390	8,449	9,160	10,082	10,918	12,458	12,939	13,255	13,60[illegible]

1/ Includes adjustment for missing countries based on estimates: 0.5% of subtotals

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in Western Europe (A Constructed Time Series, 1959 - 1980)

Country	Expenditures (000 Constant 1980 US $) 1959	1962	1965	1968	1971	1974	1977	1980	Scientist Years (Number) 1959	1962	1965	1968	1971	1974	1977	1980
Denmark	4,797	9,310	15,504	26,741	24,889	24,835	28,308	32,267	170	200	300	500	530	560	638	727
Finland	3,949	5,360	6,976	8,089	8,664	11,080	14,935	17,303	136	152	165	180	215	242	326	389
Iceland	493	559	960	754	1,064	1,298	1,583	1,422	22	20	19	19	27	35	44	47
Ireland	3,949	11,284	16,612	19,047	24,654	26,171	25,956	44,824	130	250	310	350	422	490	486	300
Norway	12,696	11,989	17,262	19,829	22,776	26,744	32,122	37,511	260	280	300	308	393	480	577	674
Sweden	6,769	14,104	20,763	26,091	29,350	28,655	34,180	40,205	100	120	170	205	250	300	359	422
U.K.	62,065	70,527	78,902	106,973	141,350	152,827	165,005	235,495	1,000	1,300	1,850	2,578	2,840	3,310	5,551	5,469
Northern Europe	94,718	123,134	156,980	207,523	252,747	271,610	303,089	409,527	1,818	2,322	3,114	4,140	4,677	5,417	7,981	8,027
Austria	3,949	3,949	5,814	8,349	10,331	8,979	10,978	13,415	80	90	100	105	110	110	134	164
Belgium	12,696	14,104	14,866	18,552	19,488	29,228	39,599	35,709	260	550	650	650	650	800	838	978
France	22,569	49,369	96,897	203,511	187,840	201,541	179,770	221,590	440	720	850	1,086	1,130	1,240	1,868	2,191
Germany	59,242	141,056	193,797	234,819	234,800	229,240	242,763	252,044	1,300	1,700	2,100	2,500	2,750	3,000	3,177	3,298
Netherlands	36,659	56,422	76,688	70,445	79,832	106,980	220,106	277,762	638	720	820	900	981	1,100	1,538	1,724
Switzerland	5,924	8,180	10,796	23,482	35,220	48,714	55,892	70,713	170	210	250	285	295	325	373	472
Central Europe	141,054	273,082	398,859	559,157	567,511	624,682	740,109	871,233	2,888	3,990	4,770	5,526	5,916	6,575	7,928	8,827
Greece	7,899	7,927	9,413	8,871	9,392	9,362	11,809	12,683	195	212	280	280	325	390	492	528
Italy	22,569	28,211	33,222	46,965	76,310	84,054	59,668	106,988	600	900	1,091	1,025	1,099	1,200	1,218	636
Portugal	4,231	7,053	8,305	11,740	18,784	19,103	19,427	19,757	300	300	350	400	450	500	372	378
Spain	4,513	9,310	13,841	31,308	46,960	53,490	60,928	69,400	450	550	580	615	640	670	1,004	1,144
Southern Europe	39,212	52,501	64,781	98,884	151,446	166,009	151,832	208,828	1,545	1,962	2,301	2,320	2,514	2,760	3,086	2,686
Regional Total	274,984	448,717	620,621	865,564	971,704	1,062,301	1,195,029	1,489,588	6,251	8,274	10,185	11,986	13,107	14,752	18,995	19,540

Appendix 1

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in Eastern Europe & USSR (A Constructed Time Series, 1959 - 1980)

	Expenditures (000 Constant 1980 US$)							Scientist Years (Number)						
Country	1959	1962	1965	1968	1971	1974	1977-80	1959	1962	1965	1968	1971	1974	1977-80
Bulgaria	11,284	13,823	15,781	27,657	37,568	38,019	38,264	250	300	350	650	981	960	966
Czechoslovakia	101,560	115,242	122,645	130,194	129,140	143,115	162,458	1,470	1,770	2,070	4,015	3,150	4,100	4,654
Hungary	5,642	7,335	33,222	67,836	61,048	69,050	67,737	400	500	1,500	1,560	1,420	1,500	1,471
Poland	22,569	39,496	57,308	69,923	77,484	93,263	95,233	1,240	2,170	3,210	4,100	4,700	5,150	5,259
Romania	19,747	33,853	49,834	61,053	68,092	82,560	95,398	650	850	1,285	1,900	2,500	3,200	3,698
Yugoslavia	14,104	14,248	14,396	20,611	28,176	34,386	35,017	1,080	1,100	1,140	1,720	1,890	1,970	2,006
Eastern Europe 1/	195,896	250,877	328,368	422,546	449,642	508,032	553,400	5,701	7,493	10,702	15,618	16,400	18,906	20,220
USSR	372,398	688,354	744,595	781,682	910,554	997,900	939,383	12,000	20,400	24,450	25,600	29,800	33,350	31,394
Regional Total	568,294	939,231	1,072,963	1,204,228	1,360,196	1,505,932	1,492,783	17,701	27,893	35,152	41,218	46,200	52,256	51,614

1/ Includes adjustment for missing countries based on estimates (% oc subtotals):

D.D.R.	11%
Albania	1%
	12%

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in Latin America
(A Constructed Time Series, 1959 - 1980)

Country	Expenditures (000 constant 1980 US$)								Scientist Years (Number)							
	1959	1962	1965	1968	1971	1974	1977	1980	1959	1962	1965	1968	1971	1974	1977	1980
Argentina	28,211	32,442	48,991	41,968	42,978	70,441	53,490	59,750	320	420	670	650	880	880	890	1,065
Chile	1,693	2,963	6,229	6,915	16,436	10,315	11,960	11,319	32	58	113	162	171	192	171	177
Paraguay	423	564	554	730	775	1,146	2,529	5,357	5	10	15	20	26	31	48	63
Uruguay	761	1,411	1,385	2,087	2,348	3,437	3,399	3,821	7	35	35	60	75	100	180	222
Temperate South America	31,088	37,380	57,159	51,700	62,537	85,339	71,378	80,247	364	523	833	892	1,152	1,203	1,289	1,527
Bolivia	507	669	693	653	587	427	6,459	11,374	20	29	40	50	60	86	86	125
Brazil	11,284	22,569	41,527	60,008	70,440	114,620	130,735	174,012	200	400	800	1,350	1,650	2,000	3,121	2,935
Colombia	14,104	13,428	17,746	25,464	30,806	31,329	29,668	32,231	200	338	300	550	809	870	824	831
Ecuador	704	1,411	2,768	4,226	5,260	8,901	8,132	6,100	12	20	34	64	94	200	183	203
Guyana	348	519	814	1,198	1,380	1,851	1,601	2,678	6	10	15	23	29	36	27	41
Peru	1,073	2,104	4,154	8,479	11,740	12,895	6,871	8,163	32	65	131	155	180	220	295	290
Venezuela	6,772	11,193	13,677	19,829	17,845	15,283	34,509	34,885	100	176	184	155	226	354	329	360
Tropical South America	34,792	51,893	81,379	119,857	138,058	185,306	217,975	269,443	570	1,038	1,504	2,347	3,048	3,766	4,865	4,840
Barbados	172	103	244	295	449	593	514	652	3	4	5	7	8	10	13	23
Costa Rica	775	930	1,108	1,043	2,747	2,374	1,935	2,168	40	48	59	55	61	71	60	75
El Salvador	1,186	1,186	1,108	1,174	1,409	1,815	2,507	2,391	50	50	48	60	83	85	78	78
Guatemala	862	1,025	1,218	1,474	2,247	2,963	4,083	5,332	19	22	27	43	47	58	71	123
Haiti	86	103	122	147	225	296	356	452	8	9	11	18	20	24	33	37
Honduras	1,129	1,411	1,660	1,827	1,878	1,719	831	1,047	35	43	51	60	67	72	66	60
Jamaica	172	205	244	295	1,132	1,810	1,639	935	15	17	20	32	55	88	85	40
Mexico	5,079	5,924	6,922	8,871	14,558	22,924	20,393	70,929	190	220	280	520	540	711	1,074	1,079
Nicaragua	451	803	1,385	1,827	1,878	1,719	1,711	2,211	8	10	17	22	29	34	44	57
Panama	345	410	487	589	899	1,185	1,515	2,482	11	13	16	25	44	49	29	51
Trinidad & Tobago	172	205	244	295	449	593	832	709	10	11	14	22	23	29	39	40
Dominican Rep.	690	820	975	1,179	1,798	2,370	3,486	2,514	10	11	14	22	23	29	40	40
Caribbean & Central America 1/	13,676	16,144	19,332	23,390	36,493	49,644	48,956	112,941	491	564	691	1,090	1,230	1,552	2,015	2,167
Regional Total	79,556	105,417	157,860	194,947	237,088	320,289	338,309	462,631	1,425	2,125	3,028	4,329	5,430	6,521	8,169	8,534

1/ Includes adjustment for missing countries based on estimates (1% of subtotals):

CATIE (IICA)	4
Cuba	19
	23

Appendix 1

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in Africa (A Constructed Time Series, 1959 - 1980)

Country	Expenditures (000 Constant 1980 US$)								Scientist Years (Number)							
	1959	1962	1965	1968	1971	1974	1977	1980	1959	1962	1965	1968	1971	1974	1977	1980
Morocco	2,116	3,386	4,154	5,217	6,574	6,112	8,633	8,026	17	25	34	43	60	65	543	686
Sudan	2,820	4,513	6,922	7,828	9,580	8,213	11,388	13,600	50	50	50	55	128	140	144	150
Egypt	11,284	16,363	21,040	24,785	24,067	21,015	22,325	23,717	400	500	600	700	750	800	850	903
Tunisia	1,204	1,800	2,383	2,807	2,428	3,874	5,320	6,764	35	44	53	62	72	140	212	285
Libya	973	1,456	1,927	2,270	2,413	2,125	2,541	2,793	39	58	77	91	97	80	112	123
North Africa[1/]	20,789	31,095	41,161	48,485	50,920	46,713	56,734	62,037	590	738	887	1,037	1,207	1,335	2,028	2,340
Cameroon	564	1,129	1,684	2,374	3,052	3,437	3,364	3,788	10	15	20	48	72	96	94	106
Chad	282	564	831	1,043	1,174	1,146	1,369	1,602	7	10	16	23	26	30	36	42
Dahomey	564	1,129	1,799	1,956	2,043	1,719	2,053	2,403	7	10	13	15	16	16	16	19
Gambia	23	28	42	47	52	47	56	66	5	5	6	6	5	5	6	7
Gabon	68	80	89	124	141	239	285	334	4	4	6	5	5	5	6	6
Ghana	3,386	4,513	5,537	6,262	6,574	5,731	12,443	12,655	60	80	100	120	140	304	301	352
Ivory Coast	5,642	8,462	11,073	13,045	14,088	12,036	12,399	12,771	40	60	80	100	110	110	113	116
Liberia	94	94	141	211	282	282	360	394	14	16	25	18	14	16	18	20
Mali	845	1,411	1,738	2,869	3,992	4,393	5,246	6,141	12	15	21	16	25	35	47	68
Mauritania	115	151	207	223	259	258	402	284	3	4	6	6	7	7	11	8
Nigeria	14,104	22,569	33,222	31,308	37,568	38,207	147,429	121,840	110	170	170	195	300	300	843	1,084
Senegal	3,668	4,513	4,982	6,001	6,574	7,640	8,369	9,726	45	55	55	85	130	160	148	172
Sierra Leone	282	394	444	470	564	573	687	698	16	22	28	23	30	36	34	35
Upper Volta	451	507	636	730	740	669	1,087	1,105	5	6	7	10	10	11	12	12
Zaire	8,462	4,797	6,922	7,828	8,230	8,608	5,949	5,095	20	25	35	30	66	85	113	97
West Africa[2/]	44,333	57,892	79,750	85,664	98,133	97,733	231,723	205,737	412	572	676	805	1,099	1,398	2,068	2,466

Appendix 1

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in Africa (continued)

Country	Expenditures (000 Constant 1980 US$)								Scientist Years (Number)							
	1959	1962	1965	1968	1971	1974	1977	1980	1959	1962	1965	1968	1971	1974	1977	1980
Burundi	282	423	721	1,043	1,017	958	3,332	3,608	10	13	16	20	24	27	22	41
Ethiopia	845	1,411	2,214	3,372	3,412	3,437	3,370	3,400	8	12	25	30	52	65	110	155
Kenya	1,411	1,975	3,322	5,480	7,748	13,492	19,844	22,712	25	40	70	140	210	280	299	400
Madagascar	2,256	5,079	6,091	6,915	6,409	6,125	5,309	4,878	25	40	50	65	70	80	76	68
Malawi	704	1,129	1,660	2,087	2,818	3,437	4,641	5,660	15	22	35	44	57	208	242	276
Mauritius	1,411	2,116	2,768	4,567	5,870	6,208	7,450	7,879	25	30	35	41	51	61	46	50
Rwanda	564	648	664	653	859	763	894	945	9	10	8	8	16	18	23	24
Tanzania	1,552	2,116	2,768	5,480	7,748	9,933	7,436	7,214	45	60	65	60	100	145	194	212
Uganda	1,411	2,116	3,322	5,480	7,748	6,687	5,804	7,452	20	32	40	52	80	80	135	175
Zambia	1,252	2,042	2,824	4,209	7,394	7,176	5,575	5,202	21	31	41	55	81	79	104	96
East Africa 3/	12,740	20,770	28,726	42,822	55,615	63,455	69,384	75,156	221	316	420	561	808	1,137	1,364	1,632
Botswana	42	141	444	521	775	629	2,803	4,977	1	2	2	10	33	30	46	61
Lesotho	28	70	110	209	303	324	429	465	1	2	3	3	7	10	13	14
Zimbabwe	1,411	1,411	2,076	3,783	5,119	7,640	7,467	10,560	140	100	134	135	172	180	155	201
South Africa	39,496	56,422	77,519	62,619	46,960	47,758	63,441	64,519	550	720	900	900	900	1,000	1,328	1,351
Swaziland	310	437	512	521	695	669	1,357	1,306	4	6	9	11	12	12	24	23
South Africa	41,287	58,482	80,661	67,653	53,852	57,020	75,497	81,827	696	830	1,049	1,059	1,124	1,232	1,566	1,650
Regional Total	119,149	168,239	230,298	244,624	258,520	264,921	433,338	424,757	1,919	2,456	3,032	3,462	4,236	5,102	7,026	8,088

Notes: 1/ North Africa totals adjusted for missing countries (% of subtotals):

	Expenditures	Manpower
Algeria	13	9

2/ West Africa totals adjusted for missing countries (%. of subtotals):

Angola	4
CAR	2
Congo	3
Guinea	2
Niger	2
Benin	1
Guinea-Bissau	1
	15

3/ East Africa totals adjusted for missing countries (% of subtotals):

Mozambique	7
Somalia	2
	9

Appendix 1

Appendix Table 1: Agricultural Research Expenditures and Scientist Years in Asia (A Constructed Time Series, 1959-1980)

Country	Expenditures (000 constant 1980 US$) 1959	1962	1965	1968	1971	1974	1977	1980	Scientist Years (Number) 1959	1962	1965	1968	1971	1974	1977	1980
Cyprus	423	704	831	1,005	915	944	1,599	2,410	15	18	20	24	37	54	56	58
Iran	4,231	7,448	12,458	16,699	23,480	34,386	39,840	45,163	55	110	250	360	550	580	457	518
Israel	11,566	14,104	16,335	19,568	18,314	22,578	25,558	30,209	170	220	270	327	440	500	566	630
Jordan	128	175	243	339	427	852	869	849	6	8	14	17	23	40	38	35
Turkey	4,797	6,206	9,690	16,960	21,367	22,924	24,640	26,463	150	200	397	440	485	540	580	623
Syria	282	704	1,219	2,219	2,700	3,057	4,045	4,963	5	10	15	40	75	110	145	179
West Africa 1/	24,427	33,449	46,485	64,741	76,611	96,605	110,068	125,465	457	645	1,101	1,377	1,835	2,079	2,100	2,329
Bangladesh	-	-	-	-	2,348	2,677	15,735	27,613	-	-	-	-	150	190	1,234	1,320
Sri Lanka	3,104	3,940	4,982	6,286	6,340	5,731	4,244	5,057	50	65	80	95	105	130	287	422
Nepal	906	1,109	1,337	1,519	2,163	2,229	2,556	2,634	71	87	104	119	169	184	223	226
India	24,825	29,622	41,020	45,717	66,108	66,868	103,855	120,167	1,150	1,160	1,450	1,800	1,950	2,150	2,244	2,345
Pakistan	2,256	3,396	4,982	5,741	4,696	4,776	38,528	29,899	120	180	270	350	250	280	1,560	1,212
South Asia 2/	32,024	39,199	53,891	61,041	84,105	84,749	169,866	190,931	1,433	1,537	1,961	2,435	2,703	3,022	5,711	5,691
Indonesia	564	2,256	4,705	6,783	8,688	8,023	42,229	33,200	15	70	140	240	340	592	914	1,473
Malaysia	3,386	5,924	9,136	9,653	11,740	11,463	19,564	30,391	40	30	150	156	195	149	284	396
Philippines	2,781	3,633	4,255	4,877	5,499	6,844	8,637	9,533	200	330	400	500	600	620	630	640
Thailand	1,552	4,231	7,476	9,652	11,740	11,463	23,547	21,600	150	250	350	475	600	725	1,134	1,264
Southeast Asia 3/	9,028	17,488	27,873	33,752	41,057	41,194	102,435	103,249	441	774	1,135	1,494	1,891	2,274	3,229	4,102
China	54,166	169,265	332,223	469,638	535,344	623,434	633,420	643,555	1,250	4,000	8,000	11,000	13,560	16,000	17,000	17,272
Hong Kong	141	183	195	195	200	190	118	132	9	8	8	8	10	12	8	8
Japan	135,414	197,479	334,992	420,064	575,260	611,306	645,543	684,276	7,200	8,500	10,000	11,500	13,700	14,000	14,784	15,671
South Korea	2,538	2,820	3,322	4,567	23,381	24,400	26,607	29,012	300	323	340	450	744	807	880	960
Taiwan	1,975	3,245	3,877	4,539	5,400	5,539	12,520	14,000	250	273	310	350	375	400	404	452
East Asia 4/	141,469	205,765	345,809	433,659	610,283	647,849	691,636	734,694	7,837	9,194	10,765	12,431	15,008	15,371	16,237	17,262
Regional Total	261,114	465,166	806,291	1,062,831	1,347,400	1,491,831	1,707,425	1,792,894	11,418	16,150	22,962	28,737	34,937	38,746	44,272	46,656

Notes:

1/ West Asia totals adjusted for missing countries based on estimates (% of subtotals):

Iraq	2
Lebanon	6
Others	6
	14

2/ South Asia totals adjusted for missing countries based on estimates (% of subtotals):

Afghanistan	2
Others	1
	3

3/ Southeast Asia totals adjusted for missing countries based on estimate (5% of subtotals). Missing countries: Burma, Cambodia, Laos, Portuguese Timor, Singapore, Vietnam.

[illegible] for missing countries based on estimates (1% of

Appendix Table 2: Agricultural Extension Expenditures and Worker Years in Western Europe (A Constructed Time Series, 1959-1980)

Country	Expenditures (000 Constant 1980 US$)							Worker Years (Number)							
	1959	1962	1965	1968	1971	1974	Average 1977-80	1959	1962	1965	1968	1971	1974	1977	1980
Denmark	15,516	16,927	17,995	20,873	21,132	19,103	22,340	742	788	790	945	947	949	951	954
Finland	12,414	16,081	20,460	18,786	18,784	24,835	26,720	670	750	861	825	750	743	685	634
Iceland	704	845	970	939	939	956	1,192	42	41	42	42	43	44	47	51
Ireland	5,079	6,488	8,305	9,392	13,384	14,137	17,309	345	385	436	465	504	540	551	578
Norway	11,848	12,977	13,841	14,351	12,679	10,125	15,047	666	678	650	645	640	640	815	989
Sweden	13,823	14,952	15,781	15,915	15,262	13,182	16,584	740	800	844	852	817	705	760	815
U.K.	53,600	67,707	80,288	99,147	112,704	93,603	114,886	1,588	1,693	1,650	1,700	2,100	2,300	2,419	2,554
Northern Europe	112,983	135,977	157,640	179,403	194,884	175,943	213,078	4,793	5,130	5,273	5,474	5,801	5,921	6,228	6,575
Austria	11,284	14,104	16,612	18,260	18,784	17,192	22,619	726	700	700	680	650	620	699	777
Belgium	1,242	1,552	1,827	2,010	2,066	1,911	2,773	345	398	340	284	280	275	342	409
France	23,132	28,702	83,056	75,664	65,744	70,874	139,796	2,460	3,668	4,400	5,200	5,700	6,300	6,530	6,790
Germany	49,369	57,834	63,675	62,098	61,048	53,490	57,698	2,936	4,400	4,400	4,500	4,812	5,100	4,714	4,874
Netherlands	15,234	23,980	31,839	37,821	41,090	39,352	27,800	1,228	1,598	1,500	1,500	1,500	1,250	1,446	1,471
Switzerland	2,820	3,808	4,705	6,391	7,396	7,640	9,336	170	270	370	480	505	530	555	582
Central Europe	103,082	146,417	201,714	202,254	196,128	190,460	260,022	7,865	11,034	11,710	12,644	13,447	14,075	14,286	14,903
Greece	3,668	4,034	4,318	4,226	3,569	3,344	3,933	330	440	400	480	839	900	907	913
Italy	11,284	19,747	29,071	37,831	37,568	33,431	42,046	2,000	2,500	2,500	3,050	3,250	3,500	3,772	4,042
Portugal	845	5,642	10,244	10,697	10,566	9,552	12,009	500	650	692	850	970	1,100	1,185	1,270
Spain	2,153	8,462	13,841	18,263	19,958	18,148	23,932	500	500	700	920	1,050	1,200	1,356	1,512
Southern Europe	17,950	37,885	57,474	71,018	71,661	64,474	81,920	3,330	3,590	4,292	5,300	6,109	6,700	7,220	7,737
Regional Total	234,016	320,279	416,829	452,676	462,673	430,877	556,020	15,988	19,759	21,275	23,418	25,357	26,696	27,734	29,215

Appendix I

Appendix

Appendix Table 2: Agricultural Extension Expenditures and Worker Years in North America and Oceania (A Constructed Time Series, 1959-1980

Country	Expenditures (000 Constant 1980 US$)							Worker Years (Number)						
	1959	1962	1965	1968	1971	1974	Average 1977-80	1999	1962	1965	1968	1971	1974	1977-80
Australia	30,576	50,780	55,371	62,619	93,920	95,517	113,478	1,700	1,750	1,800	2,000	2,250	2,300	2,400
New Zealand	7,899	8,462	9,136	10,958	11,740	16,239	19,296	370	375	375	400	450	450	300
Oceania 1/	50,466	59,538	64,828	73,946	106,188	112,314	132,774	2,080	2,136	2,186	2,412	2,713	2,764	2,714
Canada	50,780	56,422	69,212	78,273	84,528	85,965	102,140	1,500	1,500	1,750	2,000	2,100	2,200	2,200
U.S.	282,112	310,323	332,223	391,365	469,600	477,583	567,388	10,000	10,000	10,200	10,400	10,600	10,800	9,653
North America	332,892	366,746	401,435	469,638	554,128	563,548	669,528	11,500	11,500	11,950	12,400	12,700	13,000	11,853
Regional Total	383,358	426,284	466,263	543,583	660,316	675,862	802,302	13,580	13,636	14,136	14,812	15,413	15,764	14,567

1/ Totals adjusted for missing countries based on estimates of 0.5% of subtotals.

Appendix I

Appendix Table 2: Agricultural Extension Expenditures and Worker Years in Latin America (A Constructed Time Series, 1959 - 1980)

Country	Expenditures (000 Constant 1980 US $)							Worker Years (Number)							
	1959	1962	1965	1968	1971	1974	Average 1977-80	1959	1962	1965	1968	1971	1974	1977	1980
Argentina	4,513	5,642	22,149	31,308	39,212	23,879	37,412	100	165	260	286	350	360	359	359
Chile	564	618	2,768	5,217	8,922	6,495	10,176	80	91	500	500	800	649	748	847
Paraguay	101	183	387	547	564	498	780	5	10	20	30	36	42	83	124
Uruguay	564	1,129	1,103	1,305	1,409	1,338	2,096	20	30	40	50	60	70	102	133
Temperate S.A.	5,741	7,572	26,413	38,378	50,106	32,210	50,464	205	296	820	866	1,246	1,121	1,292	1,463
Bolivia	282	615	387	653	383	249	1,370	48	60	73	84	81	70	87	120
Brazil	22,851	33,008	42,358	81,403	129,610	179,570	285,039	1,688	1,916	2,196	4,275	6,972	12,600	11,641	14,428
Colombia	5,924	6,318	6,424	4,696	7,514	7,640	12,593	140	161	224	287	350	425	515	609
Ecuador	564	1,723	1,583	2,087	2,348	2,292	3,778	50	115	130	145	160	270	327	387
Peru	845	3,104	9,303	5,011	5,870	5,922	9,491	80	252	420	600	780	960	1,152	1,344
Venezuela	16,363	16,589	15,863	15,889	15,027	12,799	21,097	340	355	450	622	675	735	901	1,067
Tropical S.A. 1/	47,296	61,971	76,676	110,835	163,051	210,557	336,702	2,369	2,888	3,528	6,073	9,108	15,211	14,769	18,135
Costa Rica	902	902	1,007	1,305	3,005	2,254	3,531	40	40	38	59	104	105	155	205
El Salvador	479	564	674	679	704	1,146	1,795	36	55	81	91	106	140	212	283
Honduras	394	423	369	664	751	859	1,346	35	40	40	50	63	75	164	253
Mexico	2,538	3,668	6,368	8,871	10,589	19,103	29,929	200	250	220	460	800	1,300	1,843	2,115
Nicaragua	507	704	1,038	888	939	763	1,195	16	24	32	28	30	30	43	49
Jamaica	72	94	142	186	240	362	464	126	158	159	266	426	723	949	957
Caribbean 2/	8,414	10,931	16,509	21,660	27,912	42,118	65,807	779	975	980	1,641	2,630	4,082	5,790	6,643
Regional Total	61,451	80,474	119,598	170,873	241,069	284,885	452,973	3,353	4,159	5,328	8,580	12,984	20,414	21,851	26,241

1/ Includes adjustment for missing countries (plus 1%)

2/ Includes adjustment for missing countries based on estimates (% of subtotals):

Barbados	2
Cuba	25
Guatemala	10
Haiti	19
Panama	9
Trinidad & Tobago	5
Other	2
	72

Appendix 2: Commodity Regressions Tables

This Appendix reports the regression estimates summarized in Tables 13 and 14 in the text. Regressions for each of the ten field crops plus aggregate for grains (maize-millets-sorghum) all cereals (grains, rice, wheat) and staples (beans, cassava, groundnut, potatoes and sweet potatoes) are presented. Dummy variables for commodities and countries are self-explanatory.

Each regression reports 4 tests of coefficients:

Testoo1 is a test of the significance of the marginal product of national research outside similar regions. It is a test of b.PRES1 +

b.EXTDPRES*$\overline{\text{EXTDIV}}$+b.INTRPRES*$\overline{\text{INTR}}$ = 0 where $\overline{\text{EXTDIV}}$ and $\overline{\text{INTR}}$ are means for the sample. b's are estimated coefficients.

Testoo2 is a test of the marginal product of extension outside similar regions.

b.EXTDN+b.EXTDPRES*$\overline{\text{PRESI}}$+b.INTREXT*$\overline{\text{INTR}}$ = 0

Testoo3 is a test of the marginal product of IARC research outside similar regions:

b. INTR+b.INTRPRES*$\overline{\text{PRESI}}$+b.INTREXT*$\overline{\text{EXTDIV}}$ = 0

Testoo4 is a test of the margainal product of IARC research inside similar regions:

Testoo3 sum +b.INTSR+b.INTRESSR*$\overline{\text{PRESI}}$+B.INTREXSR*$\overline{\text{EXTDIV}}$ = 0