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EDITED BY
FRED HOEFER
CARL PRAY
VERNON W. RUTTAN
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IARC Investment, National Research and Extension Investment and Field Crop Productivity

R. E. Evenson
Yale University

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 1982, and Ruttan 1983 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 HYV's and because it occurs in a number of countries. This paper reports econometric estimates of impacts on crop productivity of national investment in crop specific research, international investment in IARC research on the commodity and national investment in extension. The estimates are based on international data. The crop productivity data are for five cereal grains (maize, millets, sorghum, rice and wheat) and five staple crops (beans, cassava, groundnuts, potatoes and sweet potatoes) for 24 countries for the period 1962-82. IARC programs were initiated in each of these ten field crops at varying times over this period.[1]

Section I of the paper discusses the econometric specifications used in the study. Section II reports the estimates of the key parameters. Section III discusses the economic and policy implications of the estimates.

I. Econometric Specification

Since the focus of this study 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 on all crops.

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(F)+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 interested in the estimates of a', b', c', or 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.[3] 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' will, 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 on 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.

The most important variables in this analysis are the research and extension variables. The following factors require attention in developing these variables:

1. The appropriate form of these variables is a 'stock' form reflecting the fact that current production is affected not simply by current research and extension activities but by investments in the past.

2. Research and extension 'interact' in that the effectiveness or productivity of one activity is affected by the level of other activities. There is also a kind of 'hierarchy' of these or activities with IARC's being furthest from the farmer, national research next furthest and extension closest. The

IARC's produce new technology than can be either a substitute for or a complement to the technology produced by national research programs. If IARC technology (such as a new crop variety) is well suited or 'matched' to a nation's producing environment it will be a substitute for national research produced technology. IARC investment in this case will lower the marginal product of national research. It could be a complement to national extension by providing more technology to extend. On the other hand, easily identified technology may enable farmers to bypass traditional extension services. If IARC technology is mismatched to national production conditions it may be a complement to national research because it provides national systems with scope for adaptive research thus raising the marginal product of national research.

3. Appropriate deflators are required. In the case of extension which is not measured on a commodity basis, a deflator measuring the general size and commodity mix is required. The national research stocks are to some extent deflated by their commodity specific nature.

4. Simultaneity problems may exist if national research and extension program investment responds to 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 a 'two stage least squares' procedure.

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

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

where R_t^* is predicted research spending in time t. The prediction is based on an investment analysis. (See below). The weights used were indirectly estimated by constructing an alternative stock using weights rising to one by year 8 - 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.

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

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

The following 'interaction' variable are defined:

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

The use of predicted national research data to construct the stock variables utilized in this analysis constitutes a form of two stage least squares. It is designed to correct for simultaneity bias that is due to national government response in their investment decisions to productivity gains in the commodities.

The predicting equation for national research was:

$$RES = b_0 + b_1PROD + b_2AREA + b_3CINTSP + b_4UREARICE + b_5RESNSR + b_6ECONAG + b_6ECONAG + b_7URBANPOP + b_8EXPRAT + b_9ARABLE + b_{10}DIVER + b_{11}PRODDWER + b_{12}VIOLD$$

where:

RES is expenditures on research on the commodity. This was constructed by first estimating the share of total research spent on the commodity and multipling the share by total spending. The share was estimated as the share of total 'standardized' publications devoted to research on the commodity. Publication data were from the Commonwealth Abstracts Bureau data. (See Appendix 1 for a fuller discussion). Publication data was 'standardized' using data from Brazil to convert publications into constant spending units.[5]

PROD is production of the commodity
AREA is area harvested
CINTSP is cumulated total IARC spending on the commodity
UREARICE is the ratio of urea prices to rice prices, a measure of price intervention in markets
RESNSR is scientist man years devoted to the commodity in national research programs in similar geo-climate regions
ECONAG is the proportion of the labor force in agriculture
URBANPOP is the proportion of the population in urban areas larger than 100,000 people
EXPRAT is the ratio of expenditures per research scientist to expenditures per extension worker - a proxy for the real costs of research
ARABLE is the ratio of arable land currently to arable land 6 years previously, a measure of land exhaustion
DIVER is a measure of geo-climate and commodity diversity. It is defined as $\sum_{i,j} S_{ij}^2$ where S_i is the share of the i^{th} commodity in the j^{th} climate zone in total production

PRODDIVER is PROD*DIVER
VIOLD is the proportion of the population killed by political violence in the past ten years

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 IARC's 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 on these variables measure <u>added</u> 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.

II. Crop 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. 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 were obtained for maize, millets and sorghum pooled, all cereals pooled and all staple crops pooled.

The results for stage 1 are summarized in Table 1, for stage 2 in Table 2

Table 1: Determinants of National Agricultural Research Spending
Annual Data 1963-80 - 25 Countries

Dependent Variable: Research Spending in 1980 Dollars

Independent Variables	Maize	Sorghum	Millet	Rice	Wheat
PROD	0.000024*	0.00013**	0.00074**	0.00041**	0.00047**
AREA	0.000045*	-0.000013	-0.00033**	-0.00056**	-0.00031**
CINTSP	0.000009**	0.000022*	0.000040	0.0000067*	0.000069**
UREARICE	-0.0302	-0.0503**	-0.0387*	-0.0259	0.2594**
RESNSR	0.0217**	0.0307**	0.0355**	0.0121**	-0.0556**
ECONAG	-0.0132**	-0.0124**	-0.0177**	-0.0599**	-0.0079
URBANPOP	-0.0049	-0.0064*	-0.0078*	-0.0539**	0.0241**
EXPRAT	0.0076*	-0.0109**	-0.0094*	0.0361**	0.0702**
ARABLE	-0.3481	-0.0993	-0.2721	0.0174	0.5191
DIVER	0.6024**	0.4825**	0.7590**	1.0257**	-0.2170
PRODDIVER	0.000015**	0.000019**	0.000022**	0.000038**	0.000054**
VIOLD	-696.59**	-555.88**	-616.31**	-2016.22*	-3383.09**
R^2	0.5554	0.5904	0.6905	0.7575	0.8179
F	48.94	56.46	61.12	122.32	175.95

*T ratio between 1.5 and 2.0

**T ratio greater than 2.0

Table 1 (continued)

Independent Variables	Cereals	Beans	Cassava	Groundnuts	Potatoes	Sweet Potatoes
PRØD	0.00023**	-0.00168**	0.000024**	0.00014**	-0.00007**	0.0000012
AREA	-0.00019**	0.00135**	-0.00008**	-0.000031	0.0033**	0.00011
CINTSP	0.000016**	0.0000065	-9.517E-07	0.000026	0.0000042**	0.000019**
UREARICE	-0.0971**	-0.0188	-0.0452**	-0.0144	0.0238**	-0.0426**
RESNSR	0.0129**	0.0434**	0.0672**	0.0358**	-0.0069	-0.0637**
ECONAG	-0.0286**	-0.0059*	-0.0035**	-0.0052**	-0.0122**	-0.0030*
URBANPOP	-0.0266**	-0.00049	-0.00092	-0.0021	-0.0054**	-0.0052**
EXPRAT	0.0173**	-0.0236**	0.0016	0.0052*	-0.0060**	0.0019
ARABLE	-0.1608	-0.3485	-0.7014**	0.0086	0.2074	-0.1212
DIVER	0.3572	0.4242**	-0.0632	0.4257**	-0.3061**	0.0131
PRODDIVER	0.000017**	0.000016**	-0.0000013*	0.0000057**	-0.000004**	2.967E-07
VIOLD	649.20**	-548.93**	-113.82	-181.44*	72.86	-39.83
R^2	0.6859	0.7526	0.2946	0.4169	0.6297	0.1432
F	173.45	119.15	16.36	28.00	66.61	6.55

and for stage 3 in Table 3. Appendices 1, 2, and 3 report the actual regression estimates for each stage and provide full detail on variable definitions and means.

Stage 1 is not the central focus of this analysis. However, it is an important step in the procedures leading to the main estimates to be reported in Tables 2 and 3. The rationale for the prediction equations used for research spending is summarized in Appendix 1 and developed more fully in a companion paper, 'The IARC's: Evidence of Impact on National Research and Extension Programs' (Evenson 1985).

The prediction equations are summarized in Table 1. The coefficient on production, holding area constant, can be interpreted as a partial response to yield. The purpose of the prediction procedures is to correct for this simultaneous response of investment to yield in the stage 2 and 3 crop productivity regressions. Investment responds positively to yield in all five cereal grains and cassava and groundnuts. There is a negative relationship in beans and potatoes.

National investment responds positively to IARC spending in all commodities except cassava. It also responds positively to research conducted by geo-climate neighbors in all commodities except wheat, potatoes and sweet potatoes. This responsiveness on the part of policy makers in national systems to IARC investments and to the research of geo-climate neighbors represents a rational response to the expanded research opportunities offered by this 'outside' investment.

If these outside investments produce technology that is well matched to the production environments in the country, this technology will be a good substitute for home produced technology. A rational response to the increased availability of well matched technology from abroad will be to reduce national

Table 3: 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
PRESSI	.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
IAEC 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.

spending on research. Most technology produced abroad, however, is mis-matched to some degree to national conditions. This mis-matched technology along with scientific findings produced abroad constitute 'pre-technology science capital'. This pre-technology capital raises the productivity of national research systems. The rational response to increased availability of pre-technology capital then is to increase national investment. National system responses to IARC and geo-climate neighbor research investments indicate that they see the pre-technology capital effect as dominating the matched technology effect.

Table 1 also shows that geo-climate diversity affects research spending on most commodities. An increase in diversity leads to increased spending. This response is higher the higher is the production of the commodity. Research systems recognize the fact that research programs must be designed to deal with each commodity for each region. This creates a kind of diseconomy of scale to research systems. This diseconomy is less severe the higher is the production level of the commodity.[6]

The costs of establishing a research scientist in the field relative to the costs of establishing an extension worker also affects research investment. For all field crops, a ten percent reduction in the costs of a scientist man year will lead to an increase in the number of scientists funded of 10 to 12 percent.

The second stage of this analysis is summarized in Table 2. This table reports the coefficients of the interaction terms in the model and 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 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 geoclimate 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 IARC's would be more highly matched to similar subregions and this should be manifested in lower IARC-NRES interactions in similar regions than in general. Wheat is the only case when 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 is similar regions. Of the 24 IARC interaction coefficients in Table 2 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 equations 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.[8]

The IARC elasticities presume that IARC impacts will be realized in all 24 countries in the sample.[9]

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 .005 to .0055. 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 and t+1, .2* .00058V in 7+1, .4* .00058V in t+2, .6* .00058V in t+3, .8* .00058V in t+4, and .00058V in all years thereafter. [10] The discount rate which equates this earnings stream to the initial investment is slightly over 40 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. The table below 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 to extension spending to value of product of .005. For the higher income countries it was .0075.

Internal Rate of Return	Comparable Research Elasticity Ratio of Spending to Productivity			Comparable Extension Elasticity Ratio of Spending on Productivity	
	.0003	.0025	.005	.005	.0075
10%	.0004	.004	.007	.059	.088
20%	.0001	.009	.018	.068	.102
30%	.0002	.018	.035	.077	.116
40%	.003	.028	.056	.087	.131
50%	.005	.041	.082	.096	.145
60%	.007	.056	.113	.106	.159
70%	.009	.074	.148	.116	.174
80%	.011	.094	.188	.126	.189
100%	.017	.141	.281	.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 since its impact does not last beyond 3 periods. Extension impacts on cereal grain productivity and on potatoes and sweet potatoes productivity appear to be large enough to justify the 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.[12]

The estimates for both national research and extension should be taken 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 IARC's.

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 definition 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 2 show that pooled commodity regressions tend to be more systematic than individual commodity regressions. Table 3 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 3 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-nation 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 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 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.

Table 2: 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	
COMMODITY	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.

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.

III. Policy Implications

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 limitation has 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 IARC's 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 stage 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. A companion study (Evenson

1985) examined these data and the questions more thoroughly and concluded that the stimulus was probably due to the fact that 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 impacts can stimulate national research productivity by making longer term contributions that are not necessarily picked up in these data. The IARC's 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 and from its companion study on the IARC impact on national system spending are quite clear and quite strong. Further investment in all IARC's is likely to be highly productive.[13] 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 inpacts. Furthermore investment in IARC's stimulates more national system investment than will a comparable amount of direct aid.[14]

These estimates of high productivity impact do not mean that all IARC systems are optimally organized. What they do tell us is that the IARC concept is a good one. The IARC's 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 IARC's. But a good deal more investment and institutional development is required before these systems will effectively substitute for the IARC's.

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. Since 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 be justified. The estimates in this study regarding extension are probably subject to more error than those for IARC and national research system impacts. They generally show positive impacts. They also show that even highly productive extension programs cannot justify extension spending to product 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 nothing wrong with this, but this finding suggests that more systematic study of the research-extension link is called for.

FOOTNOTES

1. Actually IARC programs for rice began in 1959 but were really only operational by 1962 or so. Also the CIMMYT program on wheat and maize actually began earlier than 1959 with the predecessor Rockefeller Foundation program.
2. These data are from the F.A.O. Production Yearbook, annual issues.

3. These questions require farm level data from a reasonably homogenous region.

4. Inferior in that the regression had higher residual squared errors.

5. The Commonwealth Agricultural Bureau maintains an extensive series of abstracting formulas, abstracting several thousand agricultural journals from virtually every country in the world. It is possible to use 'keyword' sorting to obtain counts of research papers oriented to a particular commodity for years since 1972. For each of the countries in our data set counts of publications oriented to some 21 commodities were obtained. These were standardized as discussed in Appendix 1 using Brazilian data.

6. A minimum scale or critical mean is required for a program of any substance. Many countries have established research programs for quite minor commodities (See Evenson, Blum, and Waggoner, 1981).

7. See Evenson 1975 for an extended discussion.

8. The elasticity for similar regions is the sum of the two elasticities.

9. 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, if the Peoples Republic of China is excluded from the developing world, the 24 countries in the sample account for more than 85 percent of crop production in the developing world.

10. 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.

11. No attempt to test whether the impact costs 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.

12. Some 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.

13. This is the case even though the IARC's are relatively 'high cost' institutions. Expenditures per scientists man years 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).

14. See Evenson 1985 for a discussion of this estimate.

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