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# HUMAN CAPITAL AND AGRICULTURAL PRODUCTIVITY CHANGE

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# ABSTRACT

Human Capital held by farmers and by extension agents and researchers specializing in the development and diffusion of improved technology is vital to the achievement of productivity change in agriculture. This paper reviews studies that have sought to associate human capital and agricultural productivity growth. It emphasizes the productivity contributions of research and extension specialists. More than 50 studies covering many developing countries are reviewed. With few exceptions they measure large productivity impacts and compute relatively high rates of return to public sector investments in research and extension programs.

# Human Capital and Agricultural Productivity Change

## I. Introduction

It is now more than 30 years since human capital held by farmers, farm workers and by the research and extension specialists developing and diffusing improved technology to them attained a role in production and income analysis. T.W. Schultz (1954), was a pioneer in studies showing that the human capital associated with formal schooling enabled farmers to be more productive. He also pioneered the growth accounting work that indicated the potential role for the improved agricultural technology developed by research scientists and diffused by extension agents. Griliches' (1957) work on hybrid corn and the diffusion of research discoveries targeted to different regions of the U.S. initiated a number of studies showing the economic importance of new technology.[1]

In the past 30 years numerous studies of the role of human capital in agriculture have been made. Norton and Davis (1981) reviewed more than 100 studies of research impact. Jamison and Lau (1982) reviewed more than 30 studies of farmer schooling impacts. Birkhauser, Evenson and Feder, (1988) reviewed more than 40 studies of extension impacts. These reviews showed that in spite of differences in methodologies almost all studies supported the basic propositions put forth in the original papers. Human capital, whether in the form of basic literacy or in more advanced understanding of technical relationships and management principles, has economic value because it enables more efficient and productive farms and family enterprises.[2]

The chief objective of this paper will be to address several conceptual and statistical issues pertinent to these studies and to review several recent studies where formulations take these issues into account. Conventional human capital studies (i.e., of returns to schooling) are considered only to the extent that they are part of broader studies.[3] This review shows that these recent studies continue to support the general proposition that human capital has high productive value.

## II. Conceptual Issues

Most data suited to measuring human capital impacts are not well suited to isolating the impact or contribution of a single type of humman capital to productivity or farm income. A number of studies of schooling-income relationships have been undertaken under the assumption that the effect of other types of human capital -- extension, applied research and pre-technology science -- are "constant" in that they effect all observations in a comparable way. Even where this may be a plausible assumption, as, for example, in a cross-section of farms in a small region, a number of studies have shown that the level of other types of human capital affects the return to schooling (and that the level of schooling affects the return to extension). Welch (1970) calculated, for example, that a substantial part (at least one-third) of the earnings differential realized by farmers with high levels of schooling would disappear if the flow of new technology were to be halted.[4]

Figure 1 depicts the relationship between types of human capital skills and the products that they are associated with. The products (and their associated skill types) are presented in a hierarchical fashion because each higher order product is or can be a productive input into the production process below it. The central product of agricultural research systems is the agricultural invention (5) as typified by a new crop variety.

Figure 1: Human Capital Dimensions

Human Capital Products

| | | | | | Specialists | | |
|---|---|---|---|---|---|---|---|
| Level | Description | Farmers | Extension Workers | OF-FS Researchers | Applied Agricultural Scientists | Basic Agricultural Scientists | General Scientists |
| 7 | General Science | | | | | x | xxx |
| 6 | Pre-Invention Germplasm | | | | x | xxx | x |
| 5 | Technology Invention | | | x | xxx | x | |
| 4 | Sub-invention | x | x | xxx | xx | | |
| 3 | Information Communication | xx | xxx | xx | x | | |
| 2 | Technology Choice Decision | xxx | x | x | | | |
| 1 | Farm Management Decision | xxx | x | | | | |

The term invention is used here in a broad sense and can cover mechanical, biochemical, chemical, electrical, and even managerial inventions of new technology. The development of inventions induces sub-inventions which are derivative modifications of inventions. On-farm and farming system researchers engage in sub-invention as they seek to design improved systems.[5] Much agronomic research is of this type. Some extension workers and farmers also engage in sub-invention. Communication of technical and price information, the specialty of extension systems, enhances technical choice and farm management decisions by farmers.

In agricultural research systems, product levels above (or upstream from) the actual invention of new technology also matter because they determine invention potential through the production of pre-invention "germplasm". For biological inventions there is a natural sense in which genetic resources serve a "parental" role in facilitating the development or invention of an improved plant (or animal). In a more general sense, the definition of parental material can be broadened to include not only genetic, mechanical, and chemical materials, but methods and concepts (i.e., intellectual germplasm) as well.[6]

The planned production of pre-invention germplasm in many forms is a critical activity in agricultural research systems. Many systems institutionalize such work within experiment stations and direct it toward the production of such germplasm. As depicted in the figure, general scientists produce some agricultural pre-invention germplasm, but in a less focused and directed way than do the agricultural scientists working in experiment stations.

## Spatial or Spill-in Dimensions

As one moves up the hierarchy of human capital products in Figure 1, the location specificity of the products decreases and the likelihood of product spill-in to a given location (having originated outside the location) increases.

Farm management and technology choices must be made by each farm manager and there is virtually no spill-in (or out) of these products. Information regarding technology, prices, weather, etc., does spill-in, sometimes across long distances. Inventions vary greatly in their location specificity. Crop varieties typically have a high degree of location specificity because of geno-type environment interactions. (This is especially the case for corn.) Many mechanical inventions are also location specific for similar reasons. Agricultural chemicals, on the other hand, have low location specificity and spill broadly across many environments.[7]

Sub-inventions, because they are derivative from inventions, will have a higher degree of location specificity than the inventions from which they are derived. Farming systems management recommendations, for example, may be seen as a modification or sub-invention with high location specificity. Pre-invention germplasm, on the other hand, will typically have quite low location specificity and general science may have very low location specificity.

## Spill-in and System Design

Technology system design for agriculture must respect the inherent location specificity of the products in question. A given location must have specialists in the location if the product does not spill-in (e.g., levels 1 and 2 in Figure 1). It need not have specialists in the location provided the product:

1) Is being produced outside the location in a reasonable "spill-way" (i.e., the product will spill from its origin to the location with low locational friction).

2) The receiving location has the skills to interpret and screen information relevant to the product.

In many locations in the developing world in the 1950s, the extent of real spill-ways for most agricultural technology was seriously overestimated. Many locations (even countries) felt that it was necessary to invest only in information (extension) systems and some sub-invention, and that they could forgo investing in applied agricultural research because they were located in good spill-ways. Most locations found that the spill-way gradients were actually quite high and that there were few good research programs located in these spill-ways. Thus, both national and international research programs located in the spill-ways in the tropics and sub-tropics had high payoffs. Today, a complex system of international, national, regional and branch research stations (and extension systems) has emerged in response to experience with limited spill-in of technology.

## Timing Relationships

Each human capital product in Figure 1 has a life cycle over time (which is related to the spatial dimension) in which it is produced and then enters into economic use. After use it may be superceded by another substitute or follow-on product, which to some degree builds upon the initial product. If it is superseded by a follow-on product that is an "additive" to it, its life time will be permanent even though it is rendered obsolete by the additive technology. If it is superseded by a product with incomplete additively, its impact on productivity will decline, and it will then depreciate.[8]

Farm management decisions typically have a short life because next year's decisions may depend on new information, hence additivity occurs. Technology choice decisions have a longer life. Most extension information has a relatively short life because of new non-additive information.

New technology typically has a longer life because even when inventions (e.g., varieties) are superceded by new ones, the new inventions have been built upon the old ones (through the parentage mechanism). Crop and animal technology is subject, however, to real environmental exposure losses in cases where pests and pathogens exploit this technology after exposure.

## III. Methods for Human Capital Valuation and Econometric Specification Issues

Studies of human capital contributions to agriculture have concentrated on measuring the relationship between human capital investments and farm production, profits and incomes. Relatively few studies have attempted to compute more general economic outcomes. It is convenient to classify these studies in the following categories:

A. Imputation-Accounting Studies
B. Meta-Production Function Studies
C. TFP Decomposition Studies
D. Meta-Profits Function Studies

These 4 classes of studies are in roughly chronological order in that the earliest studies in this field were of the imputation-accounting type and the meta-profits function studies are of most recent origin. The term "meta" is used here to refer to specifications which do not treat technology as fixed and given as in conventional specifications. Instead they include variables that seek to proxy flows of human capital products. These variables are usually based on measures of investment in inputs into the activity (e.g., research or extension) rather than on direct measures of the product in question. Accordingly, the hierarchical, spatial and timing dimensions discussed above must be addressed.

In general, the imputation-accounting studies have relied on proxies for human capital products more directly and hence have avoided many of the specification issues (see below). The TFP decomposition studies, however, are indirectly a form of meta-production function study, and thus the issue of human-capital variable specification arises in the same form in these studies as well.

The general treatment of these specification questions has proceeded along the following lines:

a) Hierarchical issues have been addressed by seeking more detailed measurement and classification of human capital products. Interaction variables are then used to deal with the hierarchical issues.

b) Spatial or spill-in specifications have generally been based on geo-climate data. Typically, the unit of observation for which production data are observed (e.g., the average farm in a district) can be matched to similar geo-climate regions outside the unit of observation. It is often the case that little or no actual research is conducted in the unit itself, but that research may be conducted elsewhere in (and presumably for) a similar region or sub-region. The procedure used in several studies is to form a variable:

1) $R_u' = \alpha R_u + \beta R_{ss} + \gamma R_{sr}$

where $R_u$ is the research stock variable for research conducted in the unit, $R_{ss}$ is for research conducted outside the unit in similar geo-climate sub-regions and $R_{sr}$ is for research conducted in similar geo-climate regions. Iterative methods are usually used to estimate $\alpha$, $\beta$ and $\gamma$ and hence spill-in.

c) Timing issues are addressed by forming a stock from previous investment where the timing weights $\alpha_i$ in the stock measure the life cycle impacts of research conducted in a given time period t.

2) $R_t = \sum_i W_i R_{t-i}$

Since these weights typically rise and then fall, the exponentially declining weight structure used in many distributed lag models is poorly suited to this problem.[9] Most studies have estimated periods of rising, constant and falling weights, by iterative methods. (See Evenson and Huffman, 1988.)

## A. Imputation-Accounting Studies

Imputation-accounting studies evolved from the original total factor productivity (TFP) measurement methods. Imputation-accounting methods entail the application of one or more "corrections" or imputations to the TFP data to account for TFP growth. The basic idea is that by "chipping away" at the residual TFP growth component with enough corrections and imputations one will reach a pretty complete accounting for the components of TFP growth. The pioneers in this general approach are Schultz (1954), Griliches (1957, 1960) and Denison (1963). Griliches and Jorgensen (1967) contributed a major study of this type and engaged in a debate with Denison over procedures.

The most direct corrections or imputations are those associated with human capital change. Studies of schooling-associated skills show that under the assumption that earnings differentials associated with skills were reflecting real productivity, corrections for labor quality can be made.

The foundations for the accounting approach can be developed in the following simple way:

Suppose that the true relationship between output and input is:

3) $Y = \delta F(LQ_l, MQ_m, HQ_h, Z)$

where $\delta$ is a scale economies parameter, and $Q_l, Q_m$, and $Q_h$ are quality indexes that index the units of labor (L), machines (M) and land (H) into "real" quality-constant units over time (or across observations). Z is a vector of variables that characterizes technology and infrastructure contributions not channeled through scale or factor quality.

Now suppose that we do not observe $\delta$, $Q_l, Q_m$ or $Q_h$ and simply measure:

4) $Y = F(L,M,H)$

The observed TFP growth rate from 4 will be:

5) $\overset{---}{TFP} = Y - S_l\hat{L} - S_m\hat{M} - S_h\hat{H}$ where $S_l, S_m$ and $S_h$ are factor cost shares.

The true TFP growth rate is:

6) $\overline{TFP} = \hat{Y} - S_l(\hat{L}+\hat{Q}_l) - S_m(\hat{M}+\hat{Q}_m) - S_h(\hat{H}-\hat{Q}_h) - \alpha\hat{Z} - \hat{S}\delta$

where $\alpha$ is the elasticity of product with respect to the Z variables and $\hat{S}$ is the rate of change in farm size.

Suppose further that the shares $S_l$, etc. may be measured with error

($S_l^*$, etc. are the true shares), then the difference between measured TFP growth and the correct TFP growth is

$$7)\quad \overline{\overline{TFP}}-\overline{TFP}=(S_l-S_l^*)(\hat{L}+\hat{Q}_l)+(S_m-\overset{*}{S}_m)(\hat{M}+\hat{Q}_m)+(S_h-S_h^*)(\hat{H}+\hat{Q}_h)+S_l^*Q_l+S_m^*\hat{Q}_m+S_h^*\hat{Q}_h+\alpha Z+\delta\hat{S}$$

Note that the first 3 terms are based on errors in measuring the factor shares or marginal products, and the second three are based on the failure to correct for factor quality. The technology-infrastructure term unassociated with factor quality and the scale term are also included. Griliches and others who have utilized this framework have noted that the simple specification of this model does not, by itself, mean much. To be meaningful, one must bring additional evidence to the problem. One must obtain better share (marginal product) measures and actually compute $Q_l$,$Q_m$ and $Q_n$. The definitions themselves are a tautology unless this is done.

A large literature on the measurement of $\hat{Q}_i$ based on schooling-income relationships exists and has been applied in many accounting studies. This adjustment is generally the most important accounting contribution in these studies.[10] Griliches has also made adjustments for share corrections, capital stock measurement and scale economies in the context of the above specification for agriculture (Griliches, 1962).

The methodology for studies concentrating on evaluating the contribution of agricultural technology entails the following steps:

a) Identifying the invented technology (in most cases this is a set of inventions rather than a single "invention". For example in the hybrid corn study many hybrid varieties were considered).

b) Documenting all costs associated with producing, developing and diffusing the invention(s). With hybrid corn this included all public and private costs. These costs were incurred as long as 25 or 30 years prior to the realization of benefits.

c) Estimating the cost advantage for early adopters. Some studies have utilized experiment station trials to make controlled "with-without" yield and cost comparisons. These comparisons, however, are generally not representative of farmer fields, and most studies have attempted to obtain farm level comparisons. (In the hybrid corn study both experiment stations and farm data were used.)

d) Estimating the adoption pattern and the adoption-advantage interaction. In general, a new invention(s) will be adopted first on economic units where the cost advantage is greatest. As adoption spreads, the advantage typically declines (unless, as with hybrid corn, the technology as defined is undergoing continuous change).

e) Converting c and d to a benefits stream.

Imputation studies then have generally sought to estimate the shifts in supply curves from cost data. They have also estimated (or, all too often, simply assumed) the units over which these skills apply. Generally, adoption rates are used to determine these units.

Table 1 summarizes a number of the studies of the Imputation-Accounting type.

## Table 1: Imputation-Accounting Studies

| Study | Country | Commodity | Time Period | Annual Internal Rate of Return (%) |
|---|---|---|---|---|
| Griliches, 1958 | USA | Hybrid corn | 1940-1955 | 35-40 |
| Griliches, 1958 | USA | Hybrid sorghum | 1940-1957 | 20 |
| Peterson, 1967 | USA | Poultry | 1915-1960 | 21-25 |
| Evenson, 1969 | South Africa | Sugarcane | 1945-1962 | 40 |
| Barletta, 1970 | Mexico | Wheat | 1943-1963 | 90 |
| Barletta, 1970 | Mexico | Maize | 1943-1963 | 35 |
| Ayer, 1970 | Brazil | Cotton | 1924-1967 | 77+ |
| Schmitz and Seckler, 1970 | USA | Tomato Harvester, with no compensation to displaced workers | 1958-1969 | 37-46 |
| | | Tomato Harvester, with compensation of displaced workers for 50% of earnings loss | | 16-28 |
| Ayer and Schuh, 1972 | Brazil | Cotton | 1924-1967 | 77-110 |
| Hines, 1972 | Peru | Maize | 1954-1967 | 35-40[a]<br>50-55[b] |
| Hayami and Akino, 1977 | Japan | Rice | 1915-1950 | 25-27 |
| Hayami and Akino, 1977 | Japan | Rice | 1930-1961 | 73-75 |
| Hertford, Ardila, Rocha and Trujillo 1977 | Colombia | Rice | 1957-1972 | 60-82 |
| | | Soybeans | 1960-1971 | 79-96 |
| | | Wheat | 1953-1973 | 11-12 |
| | | Cotton | 1953-1972 | none |
| Pee, 1977 | Malaysia | Rubber | 1932-1973 | 24 |
| Peterson and Fitzharris, 1977 | USA | Aggregate | 1937-1942 | 50 |
| | | | 1947-1952 | 51 |
| | | | 1957-1962 | 49 |
| | | | 1957-1972 | 34 |
| Wennergren and Whitaker, 1977 | Bolivia | Sheep | 1966-1975 | 44 |
| | | Wheat | 1966-1975 | -48 |
| Pray, 1978 | Punjab (British India) | Agricultural research and extension | 1906-1956 | 34-44 |
| | Punjab (Pakistan) | Agricultural research and extension | 1948-1963 | 23-37 |
| Avila, 1981 | Brazil | Rice | 1959-1978 | 87-119 |
| Scobie and Posada, 1978 | Bolivia | Rice | 1957-1964 | 79-96 |

## Table 1: Imputation-Accounting Studies (continued)

|  |  | Time | Annual Internal |  |
|---|---|---|---|---|
| Study | Country | Commodity | Period | Rate of Return (%) |
| Pray, 1980 | Bangladesh | Wheat and rice | 1961-1977 | 30-35 |
| Moricochi, 1980 | Brazil | Citrus | 1933-1985 | 78.3-27.6 |
| Nagy, 1987 | Pakistan | Wheat | 1967-1981 | 58 |
| Nagy, 1981 | Pakistan | Maize | 1967-1981 | 19 |
| Monteiro, 1975 | Brazil | Cocoa | 1923-1975 | 16-18 |
|  |  |  | 1958-1974 | 60-79 |
|  |  |  | 1958-1985 | 61-79 |
| Fonseca, 1976 | Brazil | Coffee | 1933-1995 | 23.6-25.6 |

Notes:
a. Returns to maize research only.
b. Returns to maize research plus cultivation "package".

Source: Evenson, 1988.

The calculated internal rates of return represent the <u>average</u> rate of return per dollar invested over the period studied, with the benefits of past research assumed to continue indefinitely. Some studies have sought to distinguish between changes in consumers' surplus and changes in producers' surplus.

## B. <u>Statistical Meta-Production Function Studies</u>

Table 2 summarizes several meta-production function studies where research extension and schooling variables have been incorporated into aggregate production function analyses. In one form or another these studies had to address the three questions discussed in Part II in specifying the research (and extension) variables. The first is the specification of research across commodities. The second is the spatial or regional issue. The third is the timing dimension.

The studies vary greatly in the specification of these variables. In some cases time series data were used and simple lags were presumed. Other studies used distributed lag methods. The Evenson-Welch study for the U.S. is one of the few to actually estimate spill-in. In this study geo-climate regions and sub-regions were defined. The study estimated crop research spill-in to be confined to geo-climate sub-regions, while livestock research impacts were confined to geo-climate regions -- hence spill-in from one state to another was quite extensive.

The estimated rates of return from these studies can be roughly interpreted as returns to marginal investment. They are calculated by computing the estimated marginal product of the research (or extension or

Table 2: Meta-Production Function Studies

| Study | Country | Commodity | Time Period | Estimated Marginal Rate of Return (%) |
|---|---|---|---|---|
| Tang, 1963 | Japan | Aggregate | 1880-1938 | 35 |
| Griliches, 1964 | USA | Aggregate | 1949-1959 | 35-40 |
| Latimer, 1964 | USA | Aggregate | 1949-1959 | not significant |
| Peterson, 1967 | USA | Poultry | 1915-1960 | 21 |
| Evenson, 1968 | USA | Aggregate | 1949-1959 | 47 |
| Evenson, 1969 | South Africa | Sugarcane | 1945-1958 | 40 |
| Barletta, 1970 | Mexico | Crops | 1943-1963 | 45-93 |
| Duncan, 1972 | Australia | Pasture Improvement | 1948-1969 | 58-68 |
| Cline, 1975 (revised by Knutson and Tweeten, 1979) | USA | Aggregate | 1939-1948 | 41-50[a] |
| | | Research and extension | 1949-1958 | 39-47[a] |
| | | | 1959-1968 | 32-39[a] |
| | | | 1969-1972 | 28-35[a] |
| Bredahl and Peterson, 1976 | USA | Cash grains | 1969 | 36[b] |
| | | Poultry | 1969 | 37[b] |
| | | Dairy | 1969 | 43[b] |
| | | Livestock | 1969 | 47[b] |
| Kahlon, Bal, Saxena, and Jha, 1977 | India | Aggregate | 1960-1961 | 63 |
| | Philippines | Rice | 1966-1975 | 75 |
| Nagy and Furtan, 1978 | Canada | Rapeseed | 1960-1975 | 95-110 |
| Davis, 1979 | USA | Aggregate | 1949-1959 | 66-100 |
| | | | 1964-1974 | 37 |
| Evenson and Welch, 1979 | USA | Crop and Livestock | 1964 | 55 |
| Salmon, 1987 | Indonesia | Rice | 1972-1977 | 133 |
| Pray and Ahmed, 1987 | Bangladesh | Aggregate | 1948-1981 | 100+ |

Source: Evenson, 1988.

schooling) variable and then computing the implicit stream of benefits from the added product from an investment in time t in region j from the time and spill-in weights.

## C. TFP Decomposition Studies

TFP Decomposition studies are closely related to the meta-production function studies because TFP measures can be derived from a production function framework. Most recent TFP measures, however, are derived from accounting relationships and use a form of "superlative" index number methodology (e.g., the Tornquist approximation to the Divisa index). They do not fully address all issues inherent in specification 5, but do deal with inflexibilities associated with the specification of the curvature of production or transformation functions.

Modern index number methods have thus enabled a great deal of flexibility in the weighting of input and output indexes. The two stage TFP decompositon procedure in which one first computes TFP measures allowing location and time period weights to vary and then pools these measures in a TFP decomposition specification has been increasingly used.

Table 3 summarizes several TFP decomposition studies.

Table 4 reports elasticity estimates and internal rates of return for a study of the International Agricultural Research system, (Evenson 1987). This study utilized data for 24 developing countries to investigate the impacts of

Table 3: Decomposition Studies

| Study | Country | Commodity | Time Period | Annual Internal Rate of Return (%) |
|---|---|---|---|---|
| Evenson, 1979 | USA | Aggregate | 1868-1926 | 65 |
| | USA | Technology oriented | 1927-1950 | 95 |
| | USA | Science oriented | 1927-1950 | 110 |
| | USA | Science oriented | 1948-1971 | 45 |
| | Southern USA | Technology oriented | 1948-1971 | 130 |
| | Northern USA | Technology oriented | 1948-1971 | 93 |
| | Western USA | Technology oriented | 1948-1971 | 95 |
| | USA | Farm management research and agricultural extension | 1948-1971 | 110 |
| Evenson, 1987 | India | Aggregate | 1959-1975 | 100+ |
| Evenson and Jha, 1973 | India | Aggregate | 1953-1971 | 40 |
| Evenson and Flores, 1978 | Asia-national | Rice | 1950-1965 | 32-39 |
| | | | 1966-1975 | 73-78 |
| | Asia-International | Rice | 1966-1975 | 74-108 |
| Flores, Evenson and Hayami, 1978 | Tropics | Rice | 1966-1975 | 46-71 |
| Nagy | Pakistan | Aggregate | 1959-1979 | 64.5 |

Notes:

a) Lower estimate for 13-, and higher for 16-year time lag between beginning and end of output impact.

b) Lagged marginal product of 1969 research on output discounted for an estimated mean lag of 5 years for cash grains, 6 years for poultry and dairy, and 7 years for livestock.

Source: Evenson 1988.

Table 4: Estimated Productivity Elasticities in Internal Rates of Return, National Research and Extension Programs and International Agricultural Research Programs - 24 Country Study

| | Cereal Grains[a] | | | Staple Crops[b] | | |
|---|---|---|---|---|---|---|
| | Latin America | Africa | Asia | Latin America | Africa | Asia |
| I. IARC | | | | | | |
| Research Programs | | | | | | |
| Estimated elasticity | .030 | .054 | .043 | .041 | .019 | .031 |
| Internal Rate of Return | >80 | >80 | >80 | 79 | 51 | 68 |
| II. National | | | | | | |
| Research Programs | | | | | | |
| Estimated Elasticity | .144 | n.s. | .144 | n.s. | .031 | .129 |
| Internal Rate of Return | 44 | - | 50 | - | 19 | 53 |
| III. National | | | | | | |
| Extension Research | | | | | | |
| Estimated Elasticity | .075 | .013 | .192 | n.s. | .120 | .069 |
| Internal Rate of Return | >80 | 34 | >80 | - | >80 | >80 |

a) Cereals include maize, millets, sorghum, wheat, rice

b) Staple crops include cassava, beans, sweet potatoes, potatoes, groundnut

IARC research in a TFP decomposition framework. International data have certain limitations for analysis, but the TFP decomposition methods allow for each country (and time period) to have different production weights. However, since IARC impacts are inherently realized across countries, one must utilize international data to capture fully their impacts. The study indicates that the IARC programs in many commodities have been effective. This study also supports the conclusion of studies in individual countries regarding the contribution of national research programs.[11]

## D. Meta-Profit Function Studies

The most recent development in the evaluation of human capital impacts is the use of meta-profits function system evaluation where human capital variables (i.e., research, extension, schooling) are incorporated directly into systems of output supply and factor demand equations. These studies represent an advance over the second generation studies in several respects; they allow for multiple outputs or products, and they allow the measurement of separate research impacts on each output supplied and on each variable factor demanded.

The methodology of the meta-profits function systems is based on the maximized profits function where farm profits are expressed as a function of all prices of variable outputs and factors and on fixed factors and meta-technology variables, (research, extension, schooling). The first partial derivatives of this function with respect to an output (or input) price is the supply (or demand) function for that output (or input). Thus a system including an equation for each output supplied and each factor demanded is estimated jointly. Each equation includes the prices and meta-technology variables.

Table 5 summarizes the research and extension impacts on output supply and variable factor demand and variable factor productivity for studies undertaken in India, the Philippines and Brazil. These are in elasticity form and should be carefully interpreted because they are estimated treating fixed factors, particularly land area and farm size, as constant. The variable factor productivity elasticities cannot then be considered to be the full impacts.

Nonetheless, these results are instructive regarding factor and product bias. On the product side, the Indian results show that strong crop biases emerge. The HYV Green Revolution impacts are widely recognized to have a factor bias toward wheat and rice. It is not always appreciated that they were biased against corn and millets and other crops. This bias for industrial crops is more than offset by a bias in favor of these crops by the Indian research system. Both the HYV's and the Indian research system are biased against the coarse cereals, corn, millets, and sorghum.

On the factor demand side, the induced innovation and appropriate technology proponents who argue that domestic origin rather than imported technology (and this is domestic origin) will be labor using and machinery saving are not supported by these data. Agricultural technology over the past 2 to 3 decades, whether originating in developing or developed countries, has had a persistent bias favoring mechanization over animal labor use and favoring fertilizer use. It has not had strong labor using biases. (Extension in India appears to have stimulated labor demand but this is in the Green Revolution region.)

## IV. Concluding Remarks

The human capital studies reviewed in this paper now constitute a cohesive

## Table 5: Estimated Comparative Impacts Elasticities of Research, HYV and Extension Programs

| | North Indian Wheat | | | Brazil | Philippines | |
|---|---|---|---|---|---|---|
| Impact on Product Supply | Research | HYVs | Extension | Research | Research | Extension |
| Wheat | .312 | .206 | -.315 | | | |
| Rice | -.083 | .124 | .332 | | | |
| Corn - millets | -.808 | -.118 | .862 | | | |
| Industrial crops | .272 | -.093 | .325 | .054 | | |
| Export crops | - | - | - | .735 | | |
| Staple crops | - | - | - | .011 | | |
| Beans | - | - | - | .011 | | |
| Animal products | - | - | - | .067 | | |
| All products | (.166) | (.035) | (.159) | (.250) | .054 | -.048 |
| Impact on Factor Demand | | | | | | |
| Labor | .102 | .105 | .142 | .063 | -.067 | -.126 |
| Animal labor | -.095 | -.001 | .253 | .020 | - | - |
| Tractors | 1.364 | -.042 | -1.180 | .106 | .096 | .168 |
| Energy | - | - | - | .417 | - | - |
| Fertilizer | 1.116 | .473 | -1.557 | .470 | .635 | .375 |
| All inputs | .124 | (.083) | (.020) | (.147) | - | - |
| Impact on Total Variable Productivity | (.042) | (-.048) | (.139) | (.10) | .088 | .055 |
| Marginal I.R.R. | | 72% | | 70+% | 70% | |

Source: Evenson 1988.

case for investment in several forms of human capital. Public sector policymakers in most developing countries have, in fact, responded to this body of evidence and have invested more in human capital. The general findings of high returns to research in developing country locations (and the implied low levels of spill-in) have altered national investment in research and extension programs. National research programs have undergone major expansion and improvement in most countries. The IARC system has also been developed in response to evidence of high returns to investment.

The record is far from complete, however. Many millions of dollars are being expended on research, extension and many types of rural development projects. In some countries no studies of economic impact have been made. Research investments are perhaps best documented and they generally show substantial impacts. Even here, however, comparative studies of types of research activities (e.g., farming systems and on-farm research) have not been made.

For extension and schooling the record is less well documented. There is a fair amount of evidence showing high impact generally from investments in settings where a research system is in place.

In contrast to the documented record for human capital investments in research, extension and schooling, there are relatively few studies of returns to investment in rural development type projects even though large expenditures on these projects have been made. Human capital studies illustrate the merit and potential for further studies documenting economic impacts of all of these projects.

## FOOTNOTES

[1] The Griliches study addressed several dimensions of technological change including the inherent location specificity of technology and the value of targeting hybrid corn research programs to specific regions.

[2] See Tables 1-5 for a summary of internal rates of returns.

[3] Jamison and Lau 1982, provide a review of schooling impact studies in agriculture. Birkhauser, Evenson and Feder 1988, review extension studies.

[4] Relatively little evidence in other studies supports a positive interaction between research and extension or schooling. Several studies do show a negative interaction between extension programs and schooling.

[5] Proponents of these research programs point out that traditional agricultural research programs tend to concentrate on a single commodity. Many farmers (indeed most) produce several commodities and most deal with system problems.

[6] For example, improvements in measurement technology, in models and in the general understanding of biological processes constitute germplasm that serves in a parental role to invention of the technology. Much technology itself can be seen as a form of germplasm, parenting "follow-on" invention and sub-invention.

[7] See Herdt et al, 1979 for a fuller development.

[8] It is important that a distinction between obsolescence and true depreciation be made in this context. Much technology becomes obsolete, but does not truly depreciate.

[9] For purposes of estimating average time lags these methods are useful.

[10] See Jamison and Lau 1982, and Denison 1970 among others.

[11] The study in question was not a full TFP decomposition study because commodity specific input data for all commodities were not available.

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