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ECONOMIC IMPACTS OF AGRICULTURAL RESEARCH AND EXTENSION

by Robert E. Evenson

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Abstract: Agricultural research and extension programs have been built in most of the world's economies. A substantial number of economic impact studies evaluating the contributions of research and extension program to increased farm productivity and farm incomes and to consumer welfare have been undertaken in recent years. This chapter reviews these studies using estimated rates of return on investment to index economic impacts. In almost all categories of studies, median (social) estimated rates of return are high, (often exceeding 40 percent) but the range of estimates was also high. The chapter concludes that most of the estimates were consistent with actual economic growth experiences.

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Economic Impacts of Agricultural Research and Extension

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I. Introduction

Agricultural research is conducted both by private sector firms supplying inputs to farm producers and by public sector experiment stations, universities and other research organizations. In the United States, agricultural research has been treated as a public sector responsibility for much of the nation's history. The U.S. Patent Office, one of the oldest government agencies in the U.S., recognizing that intellectual property right (patent) incentives were not available to stimulate the development of improved plants and animals in the 19th century, initiated programs to search for and import seeds and breeding animals from abroad.[1] After the establishment of the United States Department of Agriculture (USDA) and the Land Grant Colleges in 1862, the Hatch Act in 1878 provided for financial support for the State Agricultural Experiment Station system (SAES). Agricultural research in the public sector today is conducted in both USDA and SAES organizations and to a limited extent in general universities. Agricultural extension is also conducted by private sector firms and by public sector extension programs. Formal extension program development occurred somewhat later in the U.S. than was the case for research.[2]

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[1] Huffman and Evenson (1993) discuss the development of the U.S. research and extension system and the early role of the patent office.

[2] The Capper-Volstead Act of 1914 provided for formal extension services, but as with research programs, official government sanction and support for these programs came only after state and private experiments with precursor programs were deemed to be successful.

The development of agricultural research and extension programs in the U.S. occurred at roughly the same time that similar programs were being developed in Europe. By the beginning of the twentieth century, most of today's developed countries had agricultural research systems in place. By the middle of the twentieth century many of today's developing countries had agricultural research and extension systems as well.[3] The perceived success of both research and extension programs in the first half of the 20th century led to the judgment that these programs should be central components in the large-scale economic development programs ushered in after World War II.

Institutional, Analytic and Methodology Issues (for *Ex Post* Studies)

Today, a complex system of International Agricultural Research Centers (IARCs), National Agricultural Research programs (NARs) and sub-national or regional programs has been built covering most of the globe. Similarly, extension programs have been developed in most countries. These programs are under various forms of review and evaluation, as is appropriate given their perceived importance as public sector investments. Some of these evaluations are administrative or financial, others are informal "peer" reviews and ratings. Some reviews are economic impact evaluations, and these are the concern of this paper.

Economic impact evaluations differ from other evaluations in that they associate economic benefits produced by a program and associate these benefits with the economic costs of the program. This means computing a benefit/cost ratio and/or other associated economic calculation, such as the present value of benefits net of costs, or internal rates of return to investment.[4] Many evaluations, such as the "monitoring and evaluation" activities associated with World Bank research and extension projects, provide indicators of

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[3] See Boyce and Evenson (1975), Judd, Boyce and Evenson (1986), and Pardey and Roseboom (1993) for international reviews of investment in research and extension.

[4] Many of these evaluations also undertake growth accounting. In addition to the literature reviewed here, a "grey" literature exists. Alston, et. al. (1999) report a meta-analysis of rates of return that includes more of the grey literature than reviewed here. Unfortunately , a comparison of studies covered cannot be made as the authors stated that data from

benefits (such as the number of beneficiaries) or of project outputs (farmers visited, experiments completed, etc.) , but do not calculate actual value measures of benefits and costs. These evaluations are important and useful, but are not economic impact evaluations as defined here.

IFPRI studies will not be released until after publication of the report.

Economic impact evaluations are intended to measure whether a project or program actually had (or is expected to have) an economic impact and to associate impacts with project or program costs. They do not measure whether the project or program was designed optimally or managed and executed optimally. Many extension and research projects and programs have had significant economic impacts even though they were not as productive as they might have been.[5] Project/program design and execution issues are informed by economic impact studies, but also require other types of evaluation. Economic evaluations, however, address basic investment and resource allocation issues that other evaluations do not address.

Economic impact evaluations can be classified into *ex ante* evaluations (undertaken before the project or program is initiated) and *ex post* evaluations (undertaken after the project is initiated, sometimes after it is completed). In practice, *ex ante* project evaluations are used by international aid agencies and to some degree by national agencies to guide investments at the project level. These evaluations are seldom reported in published form. They are also seldom compared with subsequent *ex post* evaluations.[6]

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[5] Economic impact studies are often downgraded as measures of investment effectiveness because they do not directly address project/program efficiency. The recent World Bank Operations Evaluation Department (OED) Review of Agricultural Extension and Research (Purcell and Anderson, 1997) reflects this perspective. It is critical of returns to research studies because they do not address project effectiveness. Given the World Bank's use of *ex ante* project evaluation methods (stressing economic impact indicators) the OED perspective on economic impact studies is puzzling.

[6] Ex ante economic calculations can be found in project reports of the World Bank and the regional development banks (the Asian Development Bank and the Inter-American Development Bank). As noted, however, little *ex ante-ex post* work is done.

The organization of this chapter is as follows: In Part II a brief review of institutional and analytic models of extension and research impacts is presented. Some of these models have implications for the empirical specifications surveyed in later sections. Part III reviews *ex post* studies of extension impacts. A number of these studies were based on farm-level observations and methodological issues associated with these studies are addressed. Part IV reviews *ex post* studies of applied agricultural research impacts. Part V reviews studies of R&D spillovers (to the agricultural sector from private sector research and development R&D) and "germplasmic" spillovers from pre-invention science. Part VI reviews *ex ante* studies. The concluding section addresses the "credibility" of the estimates and consistency of estimated rates of return with actual growth experience.[7]

II. Institutional, Analytic, and Methodology Issues (For *Ex Post* Studies)

Extension programs seek two general objectives. The first is to provide technical education services to farmers through demonstrations, lectures, contact farmers and other media. The second is to function in an interactive fashion with the suppliers of new technology, by providing demand feedback to technology suppliers and technical information to farmers to enable them to better evaluate potentially useful new technology and ultimately to adopt (and adapt) new technology in their production systems.

Applied agricultural research programs in both the public and private sectors seek to invent new technology for specific client or market groups. The market for agricultural inventions is highly differentiated because the actual economic value of inventions is sensitive to soil, climate, price, infrastructure, and institutional settings. Models of invention typically specify a distribution of potential

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[7] There appears to be considerable skepticism regarding estimated rates of return (Ruttan, 1998). They are widely perceived to be overestimated. This is true even though the economic impacts for other projects such as rural credit programs, rural development programs, and rural infrastructure programs (roads, etc) are typically less thoroughly documented or are apparently relatively low. A recent paper (Alston et al. 1998) reporting low rates of return proclaims that appropriate time lag estimation techniques results in low returns to research and extension. Serious flaws in this paper are noted later in this review (footnote 22), but the fact that it has attracted attention attests to skepticism. This issue of skepticism is revisited in the growth accounting section of the paper where it is shown that most high rates of return to research and extension are consistent with growth experience.

inventions whose parameters are determined by the stock of past inventions and invention methods or techniques (i.e. the technology of technology production). This feature of invention calls for specifying two types of spillovers: (1) invention-to-invention spillovers (which are often spatial), and (2) science (or pre-invention science)-to-invention spillovers.

The studies reviewed here are empirical and most entail direct statistical estimation of coefficients for variables that measure the economic impacts of extension, applied research, or pre-invention science "services." All require some form of production framework. In this section alternative production frameworks are first briefly reviewed. Then a simple characterization of technological infrastructure is presented and related to extension and research programs. A more formal model of research and extension interactions is then presented. Finally, methodological issues associated with the specification of research and extension variables are discussed.

A. Production Frameworks

The starting point of economic impact studies is a productivity-technology specification. Consider the general specification of a "meta-transformation function":

$$G(Y, X, F, C, E, T, I, S) = O \qquad (1)$$

where Y is a vector of outputs

X is a vector of variable factors

F is a vector of fixed factors

C is a vector of climate factors

E is a vector of edaphic or soil quality factors

T is a vector of technology (inventions)

I is a vector of market infrastructure

S is a vector of farmer skills

There are several empirical options to identify economic impacts of a change in T (extension and research services) based on this expression. All entail meaningfully defining measures or proxies for T (as well as measuring Y, X, F, C, E, I, and S accurately).

The empirical options are:

a) To convert (1) to an aggregate "meta-production function" (MPF) by aggregating commodities into a single output measure:

$$Y_A = F(X, F, C, E, T, I, S) \qquad (2)$$

and estimating (2) with farm-level or aggregated cross-section and/or time series data.

b) To derive the output supply-factor demand system from the maximized profits function (or minimized cost function) via the Shephard-Hotelling lemma and estimate the profit function and/or its derivative output supply and factor demand functions. (This is the cost (CF) or profits (PF) production structure.)

$$\pi^* = \pi(P_y, P_x, C, E, T, I, S) \qquad (3)$$

$$M\pi^*/MP_y = Y^* = Y(P_y, P_x, C, E, T, I, S)$$

$$M\pi^*/MP_x = X^* = X(P_y, P_x, C, E, T, I, S)$$

c) To derive "residual" total factor productivity (TFP) indexes from (1) and utilize a TFP decomposition specification (the PD production structure):

$$Y/X = TFP = T(C, E, T, I, S) \qquad (4)$$

d) To derive partial factor productivity (PFP) indexes from (1) and utilize a PFP decomposition specification (the PD(Y) production structure):

$$PFP\ (Y/Ha,\ Y/L\ \text{etc.}) = P(C, E, T, I, S) \qquad (5)$$

Each of these options has been pursued in the studies reviewed in this paper. Methods for estimation or measuring the relationship between T, the technology variables and the economic variables, have included direct statistical estimation of (2), (3), (4), or (5), and non-statistical use of experimental and other evidence. The options themselves have different implications and interpretations as well as having functional form implications for estimation.

The aggregate production function structure is often estimated with farm data. It requires that variable inputs, X, be treated as exogenous to the decision maker. It is typically argued in these studies that observed X vectors are profit-maximizing vectors and that these are functions of exogenous prices and fixed factors (as in (3)). This is a strong assumption in many settings. (From (2) one can compute the partial effect of T on Y, i.e., MY/MT, holding X constant, but one cannot compute the total effect of T on Y(MX/MT cannot be computed).

One of the problems with any statistical method is that one must have meaningful variation in the T variables to identify their effects. This often means resorting to data with broad geographic or time series dimensions. Such data are sometimes poorly suited to estimating production parameters. The TFP decomposition specification often has an advantage in these situations because production parameters are implicit in the TFP computations based on prices. With reasonable price data, TFP indexes can be computed over time and in some situations over cross-sections.[8] This may allow better estimates of T effects on productivity, $M({}^{Y}/_{X})/MT$.

The richest specification is the duality-based specification, (3). It has the advantage that independent variables are exogenous and it allows estimates of T impacts on all endogenous variables in the system.[9]

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[8] Approximations to a Divisia index (Tornqist/Theil) are generally regarded to be the appropriate TFP calculation method. Some growth accounting adjustments to inputs can affect the estimates of T parameters in (4). For example, adjustments for capital stock quality may effectively remove some of the contributions of research from the TFP measure. Many studies adjust for labor quality using schooling data. This, of course, eliminates the possibility for estimating schooling effects in (4), but it may improve prospects for estimating T effects because schooling S can be dropped from (4).

[9] This specification is also the most demanding of data.

The partial productivity framework suffers from the obvious fact that these measures are affected by other factors not included in the denominator. Nonetheless, given widely available yield and area data, some useful studies can be undertaken in this framework.

B. Technological Infrastructure and Institutions

Agricultural extension and research programs contribute to economic growth in an interactive way. The contribution of each depends on the developmental stage of the economy. Both are subject to diminishing returns. To aid in clarifying these points, consider Figure 1. Here, five different stages or levels of technology infrastructure are considered. For each, a set of yield levels is depicted for a typical crop. These yield levels should be considered to be standardized for fertilizer, water, labor, and other factor levels.

Four yield levels are depicted. The first is the actual yield (A) realized on the average farmer's fields. The second is the "best practice" yield (BP) which can be realized using the best available technology. It is possible that some farmers obtain best practice yields but the average farmer does not. The third yield level is the "research potential" (RP) yield, i.e., it is the hypothetical best practice yield that would be expected to be attained as a result of a successful applied research program directed toward this crop. The fourth is the "science potential" (SP) yield. This is also a hypothetical yield. It is the research potential yield attainable if new scientific discoveries (e.g., in biotechnology) are made and utilized in an applied research program.

Associated with these yields we can define three "gaps." The "extension gap" is the difference between best practice (BP) and average (A) yields. Extension programs are designed to close this gap. The "research gap" is the difference between research potential (RP) yields and best practice (BP) yields. Applied research programs, if successful, will close this gap (and will thus open up the extension gap). Similarly, a "science gap" exists between science potential (SP) and research potential (RP) yields.

Consider technology infrastructure stage I. This is a stage where little extension, research or science is being undertaken. Farmer schooling levels are low, markets are poor and infrastructure lacking.[10] The extension gap is large in this stage and thus there is considerable scope for a high payoff to extension, even if there are few effective research programs that are raising best practice yields. After extension programs have achieved a transition to stage II, the extension gap will have been reduced to some fraction of its original size (EXTGAP 1). The gains from reducing the original gap (EXTGAP 2) may be quite large and they are "permanent" in the sense that they are long-term gains that could not have been produced by other programs (at least not in a short time period).

Once an economy achieves stage II, it has exploited EXTGAP 2. There is further scope for extension contributions but they are not what they were in stage I (EXTGAP 1). In fact, the economy now becomes dependent on the closing of the research gap to open up the extension gap. As the economy is transformed from stage II to stage III a direct link between research and extension is forged. Extension programs now become responsible for extending relatively newly developed technology to farmers.

When pre-invention science becomes more effective, the research potential yield (RP) is raised and with active research and extension programs the economy may move into stage IV. Further progress, i.e., to stage V and beyond, depends on effective pre-invention science, research and extension programming.

Consider the situation in Africa and Asia. It appears that much of Africa has not made the transition yet to stage II and there is limited evidence that it has achieved a transition to stage III where research systems are producing significant flows of new technology suited to farmers in most regions. This is in contrast to the situation in both South and Southeast Asia where by the mid-1960s many economies were already in stage II and where “green revolution” technology in rice, wheat, corn, and other crops has enabled

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[10] Many countries in Sub-Saharan Africa fit this description.

them to make the transition to stage III. Today in some Asian countries, there are prospects for moving to stage IV.

It is possible that spill-ins from abroad can raise best practice yields before economies have made the transition to stage II. Most research gains , however, have been realized in economies that have already achieved stage II market, infrastructure and skill levels. In some cases this has been induced by the development (often in international centers) of genetic resources and methods that increase the RP yield levels. In Africa these RP yield levels for some countries may be quite low because of limited genetic resources and difficult disease and insect problems, so that the research gap is actually quite small. If this is the case, "stimulus from above" in the form of improvements in science (closing of the science gap) may be required to achieve better research performance.

C. Formal Models

The economics literature includes models of technology diffusion, of invention and of growth. In practice, these literatures are not well integrated. Technology diffusion (adoption) models typically consider technology to have already been produced and address the mechanisms of diffusion — usually employing a logistic or sigmoid functional form. Models of invention do integrate research and extension activities and are probably most useful for providing structure for the activities discussed in an informal way in Figure 1. The "new endogenous growth" literature has some insights to offer as regards R&D and invention but does not effectively integrate the invention model perspective into formal growth models.[11]

As noted earlier, extension programs are designed to (a) provide general technical adult education services and (b) to facilitate the evaluation and adoption of recently developed technology. The technology diffusion literature specifies a logistic form for the adoption of technology:

$$T_i^* = 1 / (1 - \exp(a + bt + cEXT) \qquad (6)$$

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[11] The models of Romer (1986, 1990) provide a serious treatment of invention but do not effectively address spillovers.

This functional form is relevant to adoption studies (the second function of extension) but not necessarily to studies where the first function of extension is important.[12]

Invention models can be combined with diffusion specifications, but typically are not. Consider an invention discovery model based on a simple random search model. For a given distribution of potential inventions the probability of making an invention for the n th draw from any distribution is $^1/_n$. An invention must have a higher quality index (eg. The yield of a plant variety) than previous discovered inventions. The expected cumulative number of inventions from n experiments (or draws) in a given distribution is:

Install Equation Editor and double-click here to view equation. $^1/_i$ Install Equation Editor and double-click here to view equation.

(7)

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[12] This is usually estimated by taking logarithms (Feder et al. 1985).

This expression for research discoveries was first derived by Evenson and Kislev (1976) for an exponential distribution of potential inventions. Kortum (1994) generalized this expression for any search distribution.[13]

Expression (7) relates inventions (I) to research (n). Empirical work relating research to productivity requires the further step of relating inventions to productivity. Kortum (1994) derives the standard relationship between research and productivity used in industrial studies

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where RESS is the cumulated research stock (net of depreciation).[14]

Since empirical studies are undertaken using data where extension services are not constant and where the underlying parameters of applied invention search are also not constant, the empirical specification should be extended to include extension variables and pre-invention research variables.

Extension has two effects on productivity. Most importantly, it speeds up the rate of adoption of inventions by farmers. This role is subject to diminishing returns in a manner similar to invention, calling for a Rn (EXT) term. However, extension can influence inventions as well. It can facilitate inventions by conveying farmer evaluation signals to inventors more rapidly. It can also help inventors to identify unpromising search avenues and this changes the parameters of the underlying invention search distribution. This argues for a Rn (EXT) x Rn (RESS) term.

$$\mathrm{Rn}\,(TFP) = a + b\,\mathrm{Rn}\,(RESS) + c\,\mathrm{Rn}\,(EXT) + d\,\mathrm{Rn}\,(RESS)\,\mathrm{Rn}(EXT) \qquad (9)$$

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[13] This semi-logarithmic approximation is accurate when n is large.

[14] Evenson and Kislev (1976) utilized an exponential distribution of potential inventions. They showed that the logarithmic approximation held for this distribution as well.

Pre-invention science is designed to change the parameters of the underlying search distribution as well. These discoveries may shift the mean of the underlying search distribution leading to an added term for pre-invention science.

$$\ln(TFP) = a + b \ln(RESS) + c \ln(EXT) + d \ln(RESS) \ln(EXT) + e \ln(PRINV) \qquad (10)$$

Pre-invention science may also shift the variance of the underlying distribution as well calling for an added interaction term in TFP decomposition specifications.

$$\ln(TFP) = a + b \ln(RESS) + c \ln(EXT) + d \ln(RESS) \ln(EXT) + e \ln(PRINV) + f \ln(PRINV) \ln(RESS) \qquad (11)$$

Few of the studies reviewed below were motivated by the model described here. It does, however, have some functional form implications, and while they were generally not imposed or even recognized in reported studies, the interpretative insights of the model will be useful in discussing the findings of the studies.[15]

D. Specifying Research and Extension Variables in Empirical Studies

Most of the studies reviewed in subsequent sections utilized a statistical specification of one of the production frameworks discussed above. This requires the development of research and extension variables that are appropriate to the unit of observation. These variables are conceptually similar to capital stock variables that measure capital service flows to the unit of observation. The observation may be a farm or an aggregate of farms. Production or productivity may be measured in level form or in rate-of-change form. The observation is typically for a given location and period.

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[15] Note that this model is not a simple "linear model of science" where PRINV recharges the invention pool and inventions determine the productivity of extension. Extension and research have "upstream" effects. However, the idea of exhaustion of invention pools, or of attempting to invent when the pool has not really been created , is relevant to research policy making.

Research and extension service flow variables then need to consider time weight, spatial weight and deflator issues.

1. Time weights

Research and extension programs have economic impacts that typically last for more than one period. Accordingly, the services provided by these programs to a given location in a given period may be based on research and extension activities undertaken in prior periods.

Figure 2 depicts alternative extension and research "time shapes." Consider the extension weights (Figure 2a). Two cases for the effects of extension activity in time t_0 on technology adoption patterns are depicted. In case 1, applicable to advanced technology infrastructure levels (see Figure 1), good substitutes for extension activities exist. Accordingly, productive technology will eventually be fully adopted in the absence of the extension program. The technology will be adopted earlier, given the presence of an extension program.

In case 2, applicable to low levels of technological infrastructure (e.g. , stage 1, Figure 1) good substitutes for extension programs do not exist. In this case, productive technology may not be fully adopted in the absence of extension programs. Extension then has both a speeding-up effect and a level effect.[16]

The "time-shape" weights associated with these two extension cases will depend on the production framework used. If the dependent variable is the level of production or of partial productivity, the time weights are as depicted in panels 1.1 and 2.1. For case 1, extension activity conducted prior to period $t\text{-}t_a$ is not relevant to the observation. For case 2 all prior extension may be relevant.

When the dependent variable is a rate of change as in a first difference or a change in a TFP index, the time weights are as depicted in panels 1.2 and 2.2. Note that in panel 1.1 there are negative weights for

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[16] The level effect can be seen as exploiting EXTGAP 2.

extension in some prior periods. This illustrates the fact that when extension has merely a speeding-up effect it does not actually have a net effect on the growth in production or productivity. For case 2 it does have an effect on the level of production and on growth.

Many of the studies reviewed here utilized a total factor productivity (TFP) decomposition framework where production data were first used to compute a TFP index. Then in a second stage this TFP measure is regressed on research and extension variables. Often the TFP measure is set at some level (1 or 100) in the base period (t_b) and then annual changes are "cumulated" in future periods. For this case the time shape weights are as depicted in panels 1.2 and 2.2 for the period $t_{b+1} - t_b$ and cumulated for subsequent periods. This produces a time shape similar to the shape depicted in panels 1.1 and 1.2 except that there is a cut-off in past activities associated with the date t_b.[17]

Research service time shape weights are also depicted for two cases (Figure 2b). In case 1 research activity in t_0 has future impacts that are depicted in three segments:[18]

segment a from t_0 to t_a in which no impact is realized
segment b for t_a to t_b in which a rising impact is realized
segment c from t_0 to 4 in which the effect is constant

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[17] That is, activities that affected only the base period and prior periods are inappropriate in the specifications because they only affect the constant term.

[18] Note that these segments are not arbitrary. Research programs do not produce immediate impacts. Their contributions rise to a peak after several periods. Utilizing a distributed log specification that does not recognize this logic can give very misleading estimates of the log structure.

In case 1, research service impacts (in the form of inventions adopted) do not "depreciate." They may become obsolete (i.e. replaced by improved inventions), but the improved inventions "build on" the inventions they displace. Thus the original inventions "live on" as part of the inventions that displace them.

In research case 2 real depreciation of inventions takes place as depicted in the segment d. This may be due to such factors as pest and pathogen responses to host plant resistance breeding improvements, or to incomplete "building on". After some point (segment e) research activity at t_0 will be "buried" in future productivity levels.[19] This is reflected in the time weight panels 2.1 and 2.2. As with extension, when the production structure is in rate of change form, the time shapes are quite different (panels 2.1 and 2.2). When cumulated TFP measures are used there is a cut-off on early research that is buried (segment c in case 1 or e in case 2) before t_b the beginning date of the TFP series. It is not appropriate to include this research (or extension) in the estimation.

Strategies for estimating time weights include:

a) "free form" estimates obtained by including a number of lagged research and/or extension variables.

b) "segment length" estimates obtained by constructing alternative lengths of the segments depicted in Figures 2a and 2b and undertaking an iterative search over segment lengths to minimize mean square error (a form of non-linear least squares estimation, (Evenson, 1968)).

c) "distributed lag" estimates obtained by imposing a functional form on the time shape -- such as a Nerlovian exponentially declining structure as a quadratic or other form.

Free form lag estimates are generally not very satisfactory because with high multicollinearity between lagged research variables, coefficients tend to oscillate between positive and negative values and only make sense when smoothed.

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[19] The contribution is buried in the sense that its contribution is no longer affecting current inventions or improvements even though the original invention may have been quite important.

Distributed lag estimates can impose very strong structure on time shapes, especially when improper or redundant (buried) lagged research is included in rate of change specifications.[20]

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[20] If buried research activities are included in a free form estimation specification they are essentially redundant variables. If they are included in a distributed lag specification with a polynomial or other form they can have a significant effect on time weight estimates. A recent paper Alston et al. (1997) claims that when "appropriate" estimation techniques are used, rates of return to research and extension are actually quite low. Their specification amalgamates research and extension time weights and includes buried activities in activities that do not contribute to TFP growth after 1950. Their free form estimates of lag weights show high rates of return. Imposing a polynomial specification with the buried activities down-weights more recent lags. This results in a substantial downward bias in rate of return estimates.

The segment length method, while crude, does allow flexibility in segment lengths while imposing reasonable shape weights for segments. (It is plausible that some form of non-parametric estimates would be an improvement.)[21]

2. Location spill-ins — spatial weights

Research and extension services have locational spill-overs. A geographic unit of observation is likely to receive services (spill-in) from activities located outside its geographic boundaries. These must be considered in developing research and extension variables.

Extension variables are perhaps easiest to deal with. Most extension services have a multi-level structure. Field staff are typically assigned to a region and to a set of client farms. Supervisory staff and subject matter specialists are typically assigned to cover more than one field staff unit. Field staff services from one region typically do not flow or "spill-in" to other regions. However, subject matter specialist services probably do. This problem for extension is generally dealt with in the context of defining "extension services supplied" variables (see Part III).[22]

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[21] The segment length method entails systematically searching for the segment length combination that minimizes means square error.

[22] Fixed effects estimations where spatial dummy variables are incorporated into the specification can have important effects on spill-in. For example, in two recent World Bank studies of Training and Visit (T&V) extension in Kenya fixed effects in the form of District dummy variables altered the results. In the original study Bindlish and Evenson (1994) argued that using District dummy variables would essentially eliminate most of the relevant cross-section variations for the farms in the seven District study. District dummies do not allow for "between district" variation. If there are substantial within-district spillovers from the subject-matter specialist and supervisory structure of the T&V system, within -district variation in staffing levels will capture little of the real differences in extension service. In later work Gautam and Anderson (1998) show that including District dummy variables does

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eliminate much of the correlation between extension services and farm productivity.

For research variables the problem of spatial weights is more serious, especially as many research studies utilize repeated cross-section observations. These observations must be appropriately matched with the locations where applied research is conducted. Most large national research systems are organized by political region (e.g. the state system in the U.S.) and thus each research center can often be associated with a region. However, units of observation in one region (state) may benefit from research done in another region even when they are not the clients of the other region. They may benefit in two ways:

1) Farmers may directly adopt inventions made in and for the other region, and

2) Researchers in the region may experience enhanced research productivity because of inventions made in the other region. (See (11) and (12) where b could be changed by inventions made in the other regions.)

Spatial spill-in has been handled in three ways in the studies reviewed. Many studies have either ignored the issue or implicitly argued that spill-ins are roughly offset by spill-outs. A number of studies have utilized geo-climate region data to specify spillovers. A small number have defined spill-over barrier measures and used these to specify spillovers.

The geo-climate region methodology is similar to the segment length estimation for time weights. Evenson (1969), Evenson and Welch (1980) and Huffman and Evenson (1993) utilized geo-climate region and sub-region data to define the research stocks for a unit of observation i as:

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where the spatial weights (S_{ij}) measured the relative importance of the neighboring research locations to region i. Searches over S_{ij} weights have also been combined with searches over time segment weights.[23]

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[23] This procedure is used in Huffman and Evenson (1993).

The use of spillover barrier indexes in a few studies suggests that these are a convenient means for estimating spatial weights over a number of locations. The spillover barrier between two locations i and j is defined as:

$$SPB_{ij} = 1 - C_{ij}/C_{ii} \qquad (16)$$

where C_{ii} is the minimum cost of producing the good in location i using the best (cost-minimizing) technology available to location i and C_{ij} is the minimum cost of producing the good in region i when producers are constrained to use location j's minimum cost technology.

Crop yield trial data, where a common set of cultivars are planted in different locations, enable one to actually measure SPB_{ij} by comparing yields in location i of the highest yielding cultivar in location i with the yield in location i of location j's highest yielding cultivar.[24] The actual spill-in variable can then be estimated as:

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where α can be estimated by non-linear techniques.[25]

3. Deflators

Deflators are needed for extension service variables for two purposes:

1) To put financial data (expenditures) into constant currency units, and

2) To account for farm contact heterogeneity.

The typical extension deflator is the number of farms or of areas served (see Part III).

Deflators for research variables are also required to put financial data into constant currency units and to correct for diversity not captured by spillover measures (see Part IV).

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[24] Evenson (1998) developed SPB indexes using international yield trial data for rice and applied then to spillover estimates in India. da Cruz and Evenson (1997) use similar procedures for Brazil.

[25] An alternative way to scale the SPB weights is $SPB_{ij}^{\alpha-\gamma}$. This can also be estimated with non-linear techniques.

III. Studies of Agricultural Extension Impacts

Studies of agricultural extension impacts can be grouped into three categories:

A. Studies based on farm level (cross-section) observations where extension services vary by observation but where it is presumed that research services do not vary by observation (Tables 1 and 2).

B. Studies based on aggregated farm production data (e.g. a district, country or state) usually in a cross-section framework, where both extension and applied research services are specified to vary by observation (and where research variables are included along with extension variables) (Table 3).

C. Studies based on aggregated farm data (usually repeated cross-section) where for reasons of data availability a variable measuring the combined services of research and extension is constructed (Table 4).

In this part, studies of the first two categories are reviewed. Discussion of the studies using a combined research-extension variable is deferred to Part IV where research variables are discussed in more depth.

Cross-section studies based on farm-level observations where research services can be considered to be constant over observations and where extension services vary should offer a good "with/without" experimental design setting in which to measure economic impacts. In cases where panel data for the same farms over time can be utilized, a "before/after" design element is added. A before/after comparison might be made when extension programs were first introduced. However, the only panel farm level data studies surveyed here of the before/after type attempted to measure the qualitative effect of a change in the design and management of extension from the traditional design to the Training and Visit (T&V) management implemented in World Bank- funded extension projects in India (Feder et al., 1985) in the early 1980s and in Kenya (Bindlish and Evenson, 1991) and Burkina Faso (Bindlish et al., 1997) in the late 1980s.[26]

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[26] In one sense, the best opportunity to achieve a before/after statistical design is at the time when extension

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programs are first introduced. The effect of a change in design as in the case of T&V management is difficult to measure.

Tables 1 and 2 report summaries of the farm observation studies. All studies reported estimated coefficients for an extension variable. The production structure used most frequently was the aggregate meta production function although several used productivity (yield) decomposition. Most studies reported statistical significance. Only a few studies actually calculated an internal rate of return (IRR), the measure of impact used to compare studies in this review.

The studies summarized in Table 1 utilized a farm-level or farm-specific extension variable. This was typically an index of extension staff-farm contact either in visits to the farm by extension staff or in farmer visits to extension meetings or demonstrations . Birkhauser et al. (1991), among others, have noted that this variable is subject to endogeneity bias. This is because at least some of the contacts are farmer-initiated. If one observes that more efficient farms have more extension contact, one cannot conclude that extension contact caused the efficiency difference. It may simply reflect the demand for information by the more efficient farmers.

A second form of endogeneity bias in farm-specific extension variables may be due to extension staff selectivity (i.e., the staff contact the best farmers more frequently). The remedy for this problem is to use a statistical procedure to deal with it (instrumental variables or 2SLS, 3SLS in a structural model). Only four of the studies covered in Table 1 utilized this remedy. These four studies did find statistically significant extension impacts, but taken as a group, the Table 1 studies do not provide overwhelming evidence for large extension contributions. Many of these studies were early (pioneering) studies, however, that contributed insights to later studies.

The extension studies summarized in Table 2 addressed the endogeneity problem with the extension variable by creating variables measuring "extension services supplied". For some studies this variable took the form of a dummy variable indicating whether a community had extension services supplied to it. For others it was a measure of services supplied per farm or per unit of land area for a defined extension region. These variables were not farm-specific, but were assigned to each farm observation in the extension region.

The extension services variables, as noted, were typically deflated by the number of farms.[27] In addition time weights in some studies were estimated using the segment length method. The India, Burkina Faso and Kenya studies all concluded that there were significant level segments (see Figure 2, case 2) and that the extension programs were probably mining EXTGAP 2 (see Figure 1). These three studies were of extension systems in countries with relative low technology infrastructure levels.

Several of the studies in Table 2 (including the T&V extension studies) report relatively high rates of return to investment. These rates of return were based on the time weights, deflators and estimated coefficients.[28]

Table 3 summarizes studies that were based on aggregated data. In some cases (Huffman, 1974; Huffman, 1964; Huffman, 1981; Cruz et al. 1982) the data were district, municipal or state averages compiled from Census of Agriculture data. In other cases production and input data from different sources reported for the district and state level were utilized. One study was international. All of these studies included both research and extension variables and in some cases schooling variables as well (research variable estimates from these studies are summarized in Part IV).

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[27] The "fixed effects" estimation issue is important here. Suppose there are District and sub-District extension programs. One can develop sub-District staff farm variables. District fixed effects will remove all between District variation. Yet there may be important and real differences in the District programs because of spatial spillovers over sub-District programs. District fixed effects will remove them. (See Bindlish and Evenson 1994 and Gautam and Anderson 1998.)

[28] The time weights are important in calculation rates of return to investment. The benefits stream from a given investment depend on these weights. The procedure for computing the benefits stream is to simulate the productivity gains from an expenditure increase in time t for future periods.

Several of the studies summarized in Table 3 were for a single cross-section, but most were for pooled cross-section-time-series data (or repeated cross-sections). The option of a farm- specific extension variable was not available to these studies and most used a staff or expenditure per farm or area ratio. Several imposed time weights. Several estimated time weights using the shape technique noted above.

Most of the studies summarized in Table 3 reported rate of return calculations. These, of course, are marginal rates of return since they are based on coefficients estimated for the extension variable (sometimes interacted with other variables). The rate of return was typically calculated by simulating a one dollar increase in extension expenditure in time t, then calculating the change in the extension variable in subsequent periods from this investment utilizing the time weights. The estimated coefficient for the extension variable then enables one to construct the "benefits stream" associated with the investment (multiplying by the units affected) and the IRR is calculated from this.

When these estimated rates of return are considered along with the Table 1 and 2 estimates, the general picture suggests a broad range of economic impacts ranging from negligible impacts to very high impacts. Table 4 summarizes studies where the technology variable was based on combined extension and research data. These estimated rates of return range from modest to very high. They will be discussed further in the next section.

IV. Studies of Applied Agricultural Research (Public Sector)

The studies reviewed in this section can be categorized into two groups. The first group of studies adopted a "project evaluation" approach and these report "average" IRRs (see Table 5).[29] The second group adopted a statistical estimation approach utilizing one of the production structures described above. This entailed the construction of a research services variable(s) and the direct estimation of a coefficient(s) for

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[29] Other reviewers describe these studies as using an "economic surplus" methodology. This is not very satisfactory since all studies calculate benefits in terms of economic surplus.

this variable. Economic impacts in the form of (marginal) IRRs were computed and reported in the studies of this group (see Table 6).

A. The Project Evaluation (Economic Surplus) Studies

The term project evaluation is used here to refer to the use of methods relying on evidence from different sources to measure economic impact.

All methods should, in principle, address locational and timing dimensions. For project evaluation studies these dimensions are generally inherent in the project setup. One of the first and most important studies of this type was the hybrid corn study by Griliches (1958). Griliches did not treat the development of a single variety of hybrid corn or even the set of varieties released in Iowa as the project being evaluated. He recognized that the project encompassed the pre-invention science (PS) entailed in inventing a method of inventing (i.e., the hybridization methodology) and covered applied agricultural research (plant breeding) in both public and private R&D programs.

Griliches also recognized spillover barriers. The pattern of adoption of hybrid corn varieties varied by state because of high degrees of locational specificity of hybrid corn varieties. Alabama did not adopt hybrid corn varieties until applied hybrid corn breeding programs were developed in Alabama, targeting varieties to the soil and climate conditions in Alabama.

The Griliches study set forth the basics of the measurement of benefits. Hybrid corn varieties, when adopted, reduce marginal and average costs, and shift the supply curve to the right (which in competition is the summation of the marginal costs of farmers above the minimum point on the average variable cost curves). Economic benefits are the change in consumer's and producer's surpluses and are measured by the area under the demand curve between the original supply curve and the shifted supply curve. Griliches noted that this area is well approximated by the change in average variable costs times the original quantityproduced. (The elasticity of demand is crucial to the division of economic surplus between consumers and producers, but only affects the size of the small triangle for measurement of economic surplus.)[30]

Griliches (1958) used farm experimental data in a with-without design to measure the average variable cost shift associated with hybrid varieties.[31] With information on adoption rates and the size of the shift, a benefit stream from 1900 to 1957 was created. A cost stream (including both public sector and private firm costs) was also estimated. Griliches (1958) then performed the standard investment calculations to compute the present value of benefits and costs in 1957:

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Griliches then computed the following ratio:

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[30] There is little evidence that supply curve shifts have a convergence pattern. There is some evidence (see Evenson and Huffman (1994)) for technology-induced increases in farm size. This would be consistent with divergent supply curve shifts. Huffman and Evenson (1993) note that different magnitudes of shifts for farms of different sizes (e.g., large farms realize shifts, while small farms do not) do not produce non-parallel supply curve shifts.

[31] This shift was estimated to be 28 percent. Many non-economists contend that new technology must have

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a significant cost advantage (e.g. doubling) before it is adopted. Most careful studies show that this is not the case.

This procedure converted the cumulated present values to flows and under the assumption that 1957 benefits (b_{57}) and costs (c_{57}) would continue indefinitely, this ratio was interpreted as a "dollars benefit per dollar cost" ratio. The ratio (approximately 7) was sometimes interpreted as a 700 percent rate of return on investment. Griliches himself later noted that it should be interpreted as a modified benefit-cost ratio, not as a rate of return (Griliches, 1991). He also computed the internal rate of return for the program (the rate of discount at which $PVB_{57} = PVC_{57}$) to be approximately 44 percent.

The Griliches study established the basic project evaluation methods for subsequent studies where project outcomes were measurable (e.g., adoption of hybrid corn varieties).

These included:

a) carefully defining the project's locational and timing dimensions;

b) measuring project costs;

c) measuring project outputs (adoption of hybrid corn varieties);

d) estimating the economic impact of project outputs, (i.e., as farm production, costs and supply);

e) converting economic impact estimates to project benefit estimates;

f) performing economic calculations for PVB/PVC, PVB-PVC and the internal rate of return where PVB = PVC.

Many of the studies summarized in Table 5 actually used statistical evidence. Some are based on time-series data only. Others used repeated cross-section data. The studies in Table 5 are distinguished from those in Table 6 in that they did not generally explicitly address the question of defining a research services variable. Most of the commodity studies summarized in Table 5, while based on partial factor productivity measures (yield changes), did attempt to correct for the "partial" bias by utilizing other input, quantity, and price data.

The 60-plus studies summarized in Table 5 covered a broad range of commodities in a broad range of countries. Almost all report high to very high internal rates of return. (Many studies reported a range of IRRs as noted in Table 5.)

B. Studies Based on Research Variable Coefficient Estimates

In Table 6 a summary of roughly 120 studies utilizing research variable coefficient estimates is made. Some of these are also included in Table 3, where extension IRRs are reported. All of these studies are based on aggregate data. A few are based on cross-section data only. A larger number are based on time-series data. Most are based on repeated cross-section data. As with Table 5, a broad range of countries and commodities are studied, and as with Table 5, most IRRs are in the high to very high range.

The studies summarized in Table 4, where research and extension expenditure data are amalgamated into a single variable, are comparable to some of the studies summarized in Table 6. As noted in the discussion of time shapes and of spatial weights and deflators, the amalgamated variables present very difficult weighting problems. For the most part, the studies summarized in Table 4 were based on crude time lags and deflators as were many of the studies summarized in Table 6. They are probably best interpreted as research studies rather than extension studies.

Relatively few of the studies summarized in Table 6 actually estimated time weights (noted as T). Relatively few incorporated geographic spill-in specificators (noted by G). Most undertook some form of deflation (sometimes via dummy variables).

Several of the studies summarized in Table 6 also included pre-invention science and industrial R&D spill-in variables (these are summarized in Part V).

Virtually all studies summarized in Tables 4 and 6 reported statistical significance for coefficient estimates of the research variable utilized. The rates of return calculated from these coefficients and the time weights cover a broad range.

As will be noted in the summary, there is a difference between evaluations of aggregate research programs and commodity research programs, with most of the very high IRRs being reported for the commodity programs. It will also be noted that the studies of applied agricultural research using project evaluation methods report fewer very high IRRs than do the studies using statistical methods.

Approximately half of the 200-plus IRRs reported in Table 6 utilized the meta production function structure. Approximately one-quarter used TFP decomposition and one-quarter used a yield decomposition structure. (Very few used the duality format in spite of its obvious richness.)

Many studies report a range of IRRs; only a few of these are average IRRs because most use statistical procedures to estimate impacts.

V. Studies of Industrial R&D Spill-in and Pre-invention Science Spill-in

Surveys of research expenditure in recent years have identified considerable industrial R&D directed toward products sold to and used in the agricultural sector. Agricultural machinery and agricultural chemicals are obvious cases where industrial R&D is directed toward the improvement of agricultural inputs. Johnson and Evenson (1998) report estimates of patented inventions manufactured in a number of industries that are used in the agricultural sector.

Early studies argued that if the product improvements resulting from this R&D were priced to reflect the full value of the improvement, agricultural productivity would be unaffected by industrial R&D. Recent studies conclude, however, that when new industrial products first come on the market they are priced to only partially capture the real value of the improvement (most new models of equipment are better buys than the equipment that they replace). This produces a spill-in impact.

Table 7 summarizes several studies incorporating industrial R&D variables. As will be noted in the summary, the social (private plus spillover) rate of return to this industrial R&D is roughly equal to the social rate of return to public agricultural research.

Another type of spill-in that is recognized in few studies is the "recharge" spill-in from pre-invention science. Many of the studies summarized in Tables 4, 5 and 6 actually covered a wide range of research program activities including many pre-invention science activities. The studies summarized in Table 8 specifically identified pre-invention expenditures and activities. It may be noted that these studies report relatively high rates of return.

VI. *Ex Ante* Studies

Research and extension programs in either public or private sector organizations require both design and resource allocation decisions. The project evaluation framework has been applied to many research and extension investment decisions. The World Bank and other lending or granting agencies require what is in effect *ex ante* impact evaluation studies as an integral part of the lending process. Yet it is probably fair to say that *ex ante* studies of research and extension lack credibility in these agencies.

Some of the problem with credibility is inherent in the high degree of uncertainty in extension and especially in research projects. As noted in an earlier section, research is subject to considerable uncertainty, including uncertainty as to the parameters of the search pool in which inventions are sought. Some of this uncertainty is associated with the fact that many of the important international and national agencies have not undertaken the *ex ante*–*ex post* evaluations required to establish credibility in *ex ante* (and in *ex post*) studies. It is of some interest to note that very few of the *ex post* studies reviewed have been completed by staff of the lending agencies or of national programs.[32]

The *ex ante* methodology as it has evolved since the early work of Fishel (1967) is based on the simple investment calculation:

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[32] The World Bank's OED study of agricultural research and extension (Purcell and Anderson, 1997) did call for higher standards of *ex ante* evaluation of extension projects (and of research projects as well) but did not attempt the *ex post*–*ex ante* comparisons required to give credibility to *ex ante* studies. It chose to stress informal *ex post* ratings of projects and was critical of existing *ex post* economic impact studies. The OED study was primarily concerned with the management and design issues associated with extension. It reached the conclusion that the Bank's T&V management focus was not the most effective management style for extension, although it is difficult to find the basis for this conclusion in the report. The *ex post* studies (see Tables 1 and 2) which concluded that T&V-managed extension programs did have an economic impact, but were less conclusive as to whether the T&V management style was more productive than alternatives, were criticized in the report.

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For a given research problem area (RPA) and a given research technique (RT) the *ex ante* analyst typically must specify the key design elements of the project and its magnitude. Thus PVC_0 is often specified initially (e.g. this could be a project seeking host plant drought tolerance through conventional breeding techniques, the project would specify the strategies, the pre-breeding activity, number of years, etc.).

Benefits can be separated into benefits per unit per year $(b/u)_t$ and units per year, U_t. At least one of these terms must be obtained by subjective probability estimation (SPE) by scientists with specialized knowledge (e.g., plant breeders with breeding experience and knowledge of genetic sources for drought tolerance). The "units" measure may also require estimation, but typically from different sources. One of the principles of *ex ante* analysis is that the best sources of information be consulted for each component.

Typically, the estimate $(b/u)_t$ has both a timing and a level effect. Since many projects are part of a sequence, it is often the case that the "achievement" estimate is stated in terms of potential achievement and achievement to date. This clarifies what is meant by remaining achievement. Then years-to-achievement estimates can be obtained associated with the potential achievement. In order to allow the source to express uncertainty about the estimate, the analyst can ask for a range of probabilities of achievement or, as in a recent rice research study, years to 25 percent achievement and years to 75 percent achievement.(Evenson et al, 1997)

Table 9 summarizes *ex ante* studies reported in various publications. Some of these studies are pure *ex ante* studies. Others are combined *ex ante–ex post* studies.

Interestingly, as noted in the next section, the rates of return computed for *ex ante* studies have less variability than those for *ex post* studies. They also have a lower mean and median.

VI. Assessing the IRR Evidence

The IRR evidence summarized in Tables 1-7 covers many studies, commodities and regions. The studies, however, cannot be regarded as a truly representative sample of economic impact studies of research and extension programs because of "selectivity" bias. This bias takes two forms. First, highly successful programs are more likely to be evaluated. Second, "unsuccessful" evaluations, i.e., evaluations showing no impact, are less likely to be published than evaluations showing impact. There are, however, two factors that suggest that this bias may not be so serious as to render comparative assessments of this evidence to be of little value or relevance. The first is that one can compare the studies covering aggregate programs with studies of specific (successful) commodity programs. The aggregate programs include both successful and unsuccessful programs. The second is that the evidence is based on a substantial part of the world's agricultural research and extension programs.

With the appropriate caveats regarding selectivity, it will be useful to assess the IRR evidence by making comparisons between programs, regions and periods. It will also be useful to assess the IRR evidence against the model discussed in Part II and against the arithmetic of growth. As noted earlier in this review, many reviewers of development experience suggest that most of the IRRs summarized here are overestimated.[33]

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[33] This perception is often accompanied by a perception that significant economic growth can be obtained with few resources. TFP methods often create the impression that some growth is a residual "manna from heaven." In practice most TFP decomposition studies show that growth is not available "for nothing." But they also show that when technology infrastructure levels are adequate, small investments in growth production can have very high returns.

Turning first to the overestimation issue. Are the high IRRs reported inconsistent with actual growth experience? Table 10 reports the growth rate implications for two extension program time weight schemes and two research program time weight schemes for IRRs of 20, 40, 60, and 100 percent.

Consider the first extension time weight program where the effect of extension is simply to speed up adoption three years earlier than it would have occurred in the absence of the program. In the short-run, i.e., in the first years after introducing the program, growth rates will be higher. But this will not produce a higher long-run rate of TFP growth.

Now consider the research programs where the contribution of the research program does not depreciate. The two weight sets represent the range of weights for most of the studies reviewed. Weight set 3 is a rapid research effect with the weights rising to the full effect in the sixth year after an investment of one percent of the value of production. A continuous program of investment of one percent of product each year must then produce TFP growth of .31 for an IRR of 20, .76 for an IRR of 40, 1.4 percent of an IRR of 60 and 2.8 percent for an IRR of 100. Weight set 4 is for a slower impact where the full effect of the program is realized in the eleventh year after investment. The growth rates required for these weights are higher, the second extension case is one where one-half of the extension contribution is permanent as in the cases where the technology infrastructure level is TI(1). The long-run growth implications of this are as noted.

IRRs for both extension and research studies are summarized in Table 11. Distributions of IRRs for a number of study categories are presented. Two features characterize virtually every category. The first is that mean and median IRRs are high. Seventy-four percent of the extension IRRs and 82 percent of the research IRRs exceed 20 percent. The second feature of the IRRs is that the range of estimates is broad. Every category (except for private sector R&D spillovers) includes studies reporting both low IRRs and high IRRs. Interestingly the category showing the narrowest range of IRRs is the *ex ante* study category.

Given the breadth of the range of IRRs in each category, it is difficult to draw strong conclusions regarding differences in means between categories. It can be noted, however, that the categories with the greatest proportions exceeding 40 percent are pre-invention science, private sector R&D, rice research, and fruits and vegetables research. Research studies have higher proportions exceeding 40 percent (59 percent) than is the case for extension studies (51 percent). Studies of commodity research programs have a higher proportion exceeding 40 percent (62 percent) than studies of aggregate research programs (57 percent).

Regional distributions vary with studies of both research and extension in Africa and have lower proportions exceeding 40 percent than in other regions. Asian research IRRs are especially high.

Actually as noted above, some of the very high IRRs are "suspect" in that they could be inconsistent with actual economic growth experience. It is of interest to note that the proportion of very high (exceeding 80 percent) IRRs is highest for statistical commodity research studies where spending ratios are lowest (and where one may well be understating real research expenditure as well). Typically, for commodity programs even in developed countries, research/commodity value ratios are well below one percent. This is particularly true in Asia where the highest proportion of very high IRRs is reported.

The relatively high proportion of very high IRRs for extension may appear suspect, but as noted above, this is probably not inconsistent with growth experience. The high proportion of very high IRRs for pre-invention science is also consistent with growth experience because spending ratios are low.

Studies of industrial R&D indicate that the private IRRs captured by firms are generally similar to IRRs for other investments made by the firm (Mairrese and Mohnen, 1997). These studies also show considerable spill-overs and indicate that the social rate of return is considerably higher than the private rate of return. The rate of return measured in the studies reviewed here is essentially the difference between the social and private IRR. Given that the public sector IRRs are actually social IRRs and reflect spillovers, the studies reviewed here suggest that the social IRRs for industrial R&D are also high and may well be of the same order of magnitude as public sector social IRRs.

It does not appear that there is a time trend in the IRRs reported. Studies for later periods show IRRs similar to studies of earlier periods.

While this review has not considered the few studies of determinants of investment in public sector agricultural research, it may be noted that the expansion of agricultural research and extension programs in the post-World War II era of economic development has been heavily aid-driven. The training of agricultural scientists, especially in the 1950s, 1960s, and 1970s, was funded by international agencies and undertaken in leading agricultural universities in developed countries. Many NARs received grants and loans from international agencies. In recent years, international support has been declining. Some national programs have developed national support bases and these will continue to function. Others have not and are vulnerable to downsizing without international support.

The evidence for economic impacts of research and extension programs is probably more complete and comprehensive than the evidence for many other development programs (e.g., agricultural credit programs). While the range of IRR estimates is wide the great majority of the IRR estimates indicate a high social rate of return to the investments made. Those high rate of returns were realized in many NARs and IARCs and extension programs. These programs were not uniform in terms of design efficiency, scientist skills or management. Most, perhaps all, of these programs could have been improved. The broad scope of the evidence for high payoff suggests considerable international spillovers (and some studies measured this). Many research and extension programs are poorly managed and often resource-constrained. Many fail to produce proper statistical analyses of field trials. The evidence reviewed here is not inconsistent with this. But it does support the original vision of development economists. Research and extension programs have afforded high payoff investment opportunities.

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Table 1: Extension Economic Impact Studies: Statistical Methods: Farm as Unit of Observation

Study	Country	Date (OLS)	Productio n Structure	Extension Variable	IRR	Comments
1. Lever (1970)	Botswana	CS(786)	MPF	Years extension available	nc	Low stat. signifance
2. Harken (1973)	Japan	CS((71)	MPF	Use of media by farms	nc	Path analysis
3. Moock (1973)	Kenya	CS(88)	PD(Y)	Extension contact factor	nc	Factor analysis
4. Patrick-Kehrberg (1973)	Brazil	CS(?)	MPF	Extension contacts	42-100+	Contacts endogenous
5. Hopcraft (1974)	Kenya	CS(674)	MPF	Extension visits	nc	Demonstrations, visits (maize)
Hopcraft (1974)	Kenya	CS(674)	MPF	Training courses, demonstration	nc	significant
6. Moock (1976)	Kenya	CS(?)	PD(Y)	Index of contacts, visits, courses	nc	significant for low schooling (maize)
7. Pachico & Ashby (1976)	Brazil	CS(101)	MPF	Extension Contacts	nc	n.s. (rice)
8. Halim (1976)	Philippine s	CS(202)	MPF	Extension contacts prior years	nc	Logged contacts significant (rice)
9. Capule (1977)	Philippine s	CS(438)	MPF	Hours by farmer in extension contacts	nc	n.s. (rice)
10. Jamison & Lau (1982)	Malaysia	CS(403)	MPF	Exposure to adult education courses	nc	m.s. (rice)
11. Pudasaini (1983)	Nepal	CS(354)	MPF	Extension Contacts	nc	n.s. (rice, maize)
12. Jamison & Moock (1984)	Nepal	CS(1070)	MPF	Dummy - recent contact	nc	n.s. (rice)

13. Feder, et al (1985)	India	CS(1500+)	PD(Y)	Dummy - extension type service	Low to high	Significant (rice)
14. Perraton, et al. (1985)	Malawi	CS(150)	PD(Y)	Extension visits to farmers	nc	S.S. (maize)
15. Cotlear (1976)	Peru	CS(550)	MPF	Extension contact dummy	nc	Potatoes S.S. one region
16. Hong (1975)	Korea	CS(895)	MPF	Extension spending in region	nc	S.S. (rice)
17. Jamison-Lau (1982)	Thailand	CS(184)	MPF	Extension available to village	nc	S.S. (non-chemical uses)
18. Jamison-Moock (1984)	Nepal	CS	MPF	Proportion of village contacted	nc	S.S. (wheat)
19. Feder, et al (1985)	India	CS	MPF	T&V management experiment	15+	T&V advantage
20. Cotlear (1986)	Peru	CS	MPF	Proportion hh's in village center	nc	S.S. in tradition region (potatoes)
21. Chen-Lau (1987)	Thailand	CS	MPF	Dummy: extension service to village	nc	n.s.
22. Deaton-Benjamin (1988)	Cote d'Ivoire	CS	PDM	Dummy: Extension agent available	nc	n.s.
23. Evenson (1988)	Paraguay	CS	ED	Hours Extension/Hectare	75-90	S.S. major crops
24. Bravo-Ureta & Evenson (1991)	Paraguay	CS	ED	Hours Extension/Hectare	nc	Coffee, Casava, ________ methods
25. Bindlish-Evenson (1991)	Kenya	CS(600)	MPF	Extension/Staff/Farm	100+	100+ timing estimated
Bindlish-Evenson (1982)	Kenya	CS(600)	MPF	Extension/Staff/Farm	88	Pre T&V
26. Bindlish, et al (1992)	Burkina Faso	CS(2000)	MPF	Extension/Staff/Farm	91	Extension

Table 2: Extension Economic Impact Studies: Statistical Methods: Aggregate Farms as Unit of Observation

Study	Country	Period of Data (Observations)	Production Structure	Extension Variable	IRR	Comments
1. Evenson & Jha (1973)	India	1953-57 CS (285)	PD	Maturity rating district	14	Interaction with research
2. Mohan & Evenson (1975)	India	1955-71 CS (140)	PD	Presence of IADP	15	Research included
3. Huffman (1974)	USA	1959-74 CS	MPF	Extension staff/farm	16	
4. Huffman (1976)	USA	1964 CS (276	MPF	Staff days/farm	110	S.S.
5. Evenson (1978)	USA	1971 CSxTS	PD	Expenditures/region	100+	Educ x Est neg
6. Huffman (1981)	USA	1979 CS (295)	MPF	Extension days/county	110	S.S.
7. Pray & Ahmed (1979	Bangladesh	1951-61 CSxTS	MPF	Expenditure/district	nc	marginal significance
		1977-86 CSxTS	MPF		nc	marginal significance
8. Librero & Perez (1987)	Philippines	1956-83 CS (27)	MPF	Expenditure/province	nc	S.S.
9. Setboonsarng & Evenson (1989)	Thailand	1953-71 CS-TS	PD(Y)	Expenditure/farm	nc	S.S.
10. Cruz et al. (1988)	Brazil	1970-75-80 Consm-Cs	PD	Expenditure/farm	ns	Public & private resource
11. Evenson (1987)	24 countries	1960-82 CSxTS	PD(Y)	Ext.Ex/geo-climate region		
	Latin America				neg 80+	Research inc
	Africa				34-80+	Research inc

	Asia				80+-80+	Research inc
12. Evenson & McKinsey (1991)	India	1956-83 CSxTS	PD(Y)	Expenditure/farm		
				Wheat	82	
				Rice	215	
				Jowar	167	
				Bajer	201	
				Maize	56	
				All	176	
13. Evenson (1994)	USA	1950-72 CSxTS states	P(D)	Expenditure/state	crops 101	________
					lvstk 89	deflated
					all 82	
14. Avila & Evenson (1996)	Brazil	1970 1970-85 CsxTS	PD	Predicted extension contacts	crops 33 lvstk 23 aggr. 19	based on predicted extension contacts
15. Evenson & Quizon (1991)	Philippines	1948-84	TFP(D)	Spending/farm		positive (low)

Table 3: Economic Impact Studies Combining Extension and Public Research

Study	**Country**	**Period of Analysis**	**Commodity**	**Production Structure**	**Method**	**IRR**	**Comments**
1. Ellias-Cordomi (1971)	Argentina	1943-63	Sugarcans	MPF		33-49	
2. del Ray-Cordomi (1975)	Argentina	1943-63	Sugarcand	MPF		35-41	

3. Mohan-Evenson (1975)	India	1959-71	Aggregate	PD	Stat	15-20	IADP
4. Pray (1978)	Punjab (India)	1906-56	Aggregate	MPF	Stat	34-44	
	Punjab (Pakistan)	1048-63		MPF		23-37	
5. Avila (1981)	Brazil	1959-78	Rice	MPF	PE (Stat)	83-119	
6. White-Havlicek	USA	1943-77	Aggregate	MPF		7-36	
7. LU, et al. (1979)	USA	1939-72	Aggregate	MPF		25	
8. Zentner (1988)	Canada	1946-79	Wheat		PE (Stat)	30-39	
9. Evenson (1979)	USA	1948-71	Aggregate	MPF		110	
10. Nagy (1983)	Pakistan	1967-81	Maize	MPF	PE (Stat)	19	
			Wheat	MPF		58	HYV
11. Feijoo-Cordomi (1984)	Argentina	1950-80	Aggregate	MPF		41	
12. daSilva (1984)	Brazil (Sao Paulo)	1970-80	Aggregate	MPF	Stat	60-102	
13. Ayers (1985)	Brazil	1955-83	Soybeans	MPF	PE (Stat)	23-53	
14. Nagy (1985)	Pakistan	1959-79	Aggregate	MPF	PE (Stat)	64	
15. Khan-Akbari (1986)	Pakistan	1955-81	Aggregate	MPF	Stat	36	
16. Newton, et al. (1987)	Peru	1981-87	Aggregate			17-38	
17. Scobie-Eveleeno	New Zealand	1926-84	Aggregate	PD	Stat	30	
18. Harvey (1988)	U.K.	1988	Aggregate		(ES)	38-44	
19. Setboonsarng-Evenson (1991)	Thailand	1991	Rice	MPF	Stat	40	

Table 4: Economic Impact Studies: Public Sector Agricultural Research: Project Evaluation Methods

Study	**Country**	**Commodity**	**Period**	**IRR%**
1. Griliches (1958)	USA	Hybrid corn	1940-1955	35-40
2. Griliches (1958)	USA	Hybrid sorghum	1940-1957	20
3. Grossfield & Heath (1966)	U.K.	Potato Harvester	1950-67	nc high HPV computed
4. Peterson (1967)	USA	Poultry	1915-1960	21-25
5. Evenson (1969	South Africa	Sugarcase	1945-1962	40
6. Barletta (1970)	Mexico	Wheat	1943-1963	90
7. Barletta (1970)	Mexico	Maize	1943-1963	35
8. Ayer (1970)	Brazil	Cotton	1924-1967	77+
9. Schmitz & Seckler (1970)	USA	Tomato Harvester	1958-1969	37-46
10. Ayer & Schuh (1972)	Brazil	Cotton	1924-1967	77-110
11. Hines (1972)	Peru	Maize	1954-1967	35-40
12. Monteiro (1975)	Brazil	Cocoa	1923-1975	16-18
			1958-1974	60-79
			1958-1985	61-79
13. Fonseca (1975)	Brazil	Coffee	1933-1995	23-25
14. Hayami & Akino (1977)	Japan	Rice	1915-1950	25-27
15. Hayami & Akino (1977)	Japan	Rice	1930-1961	73-75
16. Hertford, Ardila, Rocha &	Colombia	Soybeans	1960-1971	79-96

Trujillo (1977)				
		Wheat	1953-1973	11-12
		Cotton	1953-1972	none
17. Pee *1977)	Malaysia	Rubber	1932-1973	24
18. Peterson & Fitzharris (1977)	USA	Aggregate	1937-1942	50
			1947-1952	51
			1957-1962	49
			1957-1972	34
19. Wennergren & Whitaker (1977)	Bolivia	Sheep	1966-1975	44
		Wheat	1966-1975	-48
20. Pray (1978)	Punjab (British India) Punjab (Pakistan)	Agricultural research and extension Agricultural Research and extension	1906-1956 1948-1963	34-44 23-37
21. Scobie & Posada (1978)	Bolivia	Rice	1957-1964	79-96
22. Kislev & Hoffman (1978)	Israel	Wheat Dry farming Field crops	1954-1973 1954-1973 1954-1973	125-150 94-113 13-16
23. Pray (1980)	Bangladesh	Wheat & rice	1961-1977	30-35
24. Moricochi (1980)	Brazil	Citrus	1933-1985	78-27
25. Avila (1981)	Brazil	Rice	1957-1964	79-96

26. Nagy (1981)	Pakistan	Wheat	1967-1981	58
27. Nagy (1981)	Pakistan	Maize	1967-1981	19
28a. da Cruz, et al. (1982)	Brazil	____	1974-96	22-30
28b. da Cruz, & Avila (1983)	Brazil	EMPRABA	1977-82	20
28c. Martinex & Sain (1983)	Panama	Maize	1979-82	188
29. Bengston (1984)	USA	Forestry (Particleboard)	1975-2000	19-22
30. Feijoo (1984)	Argentina	Aggregate	1950-80	41
31. Monares (1984)	Rwanda	Potato seed	1978-85	40
32. Pinazza, et al (1984)	Brazil, Sao Paulo	Sugarcane	1972-82	35
33. Roessing (1984)	Brazil (CNPS)	Soybeans	1975-82	45-62
34. Bores & Loveless (1985)	USA	Forestry	-	9-12
Bengston (1985)	USA	Forestry	-	35-40
35. Brinkman & Prentice (1985)	Canada-Ontario	Aggregate	1950	66
36. Casimiro Herruzo (1985)	Spain	Rice	1941-80	15-18
37. Muchnik (1985	Latin America	Rice	1968-90	17-44
38. Ulrich, Furtan & Schmitz (1986)	Canada	Malting Barley	1951-88	31-75
39. Unnevehr (1986)	S.E. Asia	Rice quality	1983-84	29-61

40. Brunner & Strauss (1986)	USA	Forestry		73
41. Chang (1986)	USA	Forestry, pine		nc B/C = 16/1
42. Haygreen (1986)	USA	Forestry	1972-81	14-36
43. Newman (1986)	USA	Forestry		0-7
44. Westgate (1986)	USA	Forestry	1969-2000	37-111
46. Norton, Ganoza & Pomerada (1987)	Peru	Rice	1981-1996	17-44
		Corn	1981-1996	10-11
		Wheat	1981-1996	18-36
		Potatoes	1981-1996	22-42
		Brans	1981-1996	14-24
		Aggregate	1981-1996	17-38
47. Haque, et al (1987)	Canada	Eggs	1968-84	106-123
48. Harvey (1988)	U.K.	Aggricultural research & extension	Present	-37.5
49. Beck (1988)	U.K.	Horticultural Crop Protection	1979-2001	50
50. Ernstberger (1989)	Brazil	Rice		66-78
51. Hust, et al (1988)	Canada	Swine	1968-84	45
52. Luz Barbossa (1988)	Brazil	Aggregate	1974-97	40
53. Zachoriah, et al (1988)	Canada	Broilers	1968-84	8-4
54. Power & Russell	U.K.	Poultry feeding	present	Benefit cost rate of 10-

(1980)		research		7 ?
55. World Bank (1988)	Burkina Faso Cote d'Ivoire & Togo	Cotton		11-41
56. Zacharia et al (1988)	Uruguay	Rice	1965-85	52 including extension
57. Fox et al (1989)	Canada	Dairy	1968-84	97
59. Schwartz, et al (1989)	Senegal	Cow peas	1981-87	60-80
60. Bojaric & Echeverria (1990)	Boliva (CIAT)	Soybeans	1974-89	63-80
Norton, et al (1990)	Tunesia	Seed potato	1976-85	81

Table 5: Economic Impact Studies: Public Sector Agricultural Research: Statistical Methods

1. Tang (1963)	Japan	Aggregate	1880-58	MPF	35
2. Griliches (1964)	USA	Aggregate	1949-59	MPF	25-40
3. Latimer (1964)	USA	Aggregate	1949-59	MPF	n.s.
4. Peterson (1967)	USA	Poultry	1915-60	MPF	21-25
5. Evenson (1968)	USA	Aggregate	1949-59	MPF	47
6. Barletta (1970)	Mexico	All crops	1943-63	PD	45-93
7. Elias (Cordomi) (1971)	Argentina	Sugarcane	1943-63	MFP	33-49
8. Duncan (1972)	Australia	Pastures	1948-69	MPF	58-68
9. Evenson & Jha	India	Aggregate	1953-71	PD	40
10. Cline (1975)	USA	Aggregate	1939-48	MPF	41-50
11. del Rey (Cordomi) (1975)	Argentina	Sugarcane	1943-64	MPF	35-41
12. Bredahl & Peterson (1975)	USA	Aggregate	1937-42	MPF	56
			1947-57	MPF	51
			1957-62	MPF	49
			1967-72	MPF	34
13. Khalon, et al. (1977)	India	Aggregate	1960-73	MPF	63
			1956-73	MPF	14-64
14. Lu & Cline (1977)	USA	Aggregate	1938-72	MPF	24-31
15. Evenson & Flores (1978)	Asia (all)	Rice	1950-65	PP(Y)	32-39
	Asia (NARs)	Rice	1966-75	PP(Y)	73-78
	Asia (IRRI)	Rice	1966-75	PP(Y)	74-102
16. Flores et al. (1978)	Philippines	Rice	1966-75	PP(Y)	75

	Tropical Asia	Rice	1966-75	PP(Y)	46-71
17. Nagy & Furten (1977)	Canada	Rapeseed	1960-75	MPF	90-110
18. Kislev & Hoffman (1978)	Israel	Wheat	1954-73	MPF	125-150
		Dry farming	1954-73	MPF	94-113
		Field Crop	1954-73	MPF	13-16
19. Evenson (1979)	USA	Aggregate	1868-1926	PD	65
			1927-50	PP	95
	USA - South		1948-71	PD	130
	USA - North		1948-71	PD	93
	USA - West		1948-71	PD	95
20. Knutson & Tweeten (1979)	USA	Aggregate	1949-72	MPF (Alt)	28-47
21. Lu et al. (1979)	USA	Aggregate	1939-72	MPF	23-30
22. White et al. (1979)	USA	Aggregate	1929-77	MPF	28-37
23. Davis (1979)	USA	Aggregate	1949-59	MPF	66-100
24. Davis & Peterson (1981)	USA	Aggregate	1949	MPF	100
			1954	MPF	79
			1959	MPF	66
			1964, 1969, 1974	MPF	37
25. Hastings (1981)	Australia	Aggregate	1946-68	MPF	nc (ss)
26. Norton (1981	USA	Cash grains	1969-74	MPF	31-44
		Poultry	1969-74	MPF	30-56
		Dairy	1969-74	MPF	27-33

		Livestock	1969-74	MPF	56-66
27. Otto & Harlicek (1981)	USA	Corn	1967-79	MPF	152-212
		Wheat	1967-79	MPF	79-148
		Soybeans	1967-79	MPF	188
28. Sundquist et al (1981)	USA	Corn	1977	PP(Y)	115
		Wheat		PD(Y)	97
		Soybeans		PD(Y)	118
29. Evenson & Welch (1981)	USA	Aggregate	1969	MPF	55
30. Evenson (1982	Beazil	Aggregate	1966-74 (est)	MPF	69
31. White & Havlicek (1982)	USA	Aggregate	1943-77	MPF	7-36
32. Smith et al. (1983)	USA	Dairy	1978	MPF	25
		Poultry	1978	MPF	61
		Beef, Swine, Sheep	1978	MPF	22
33. Feijoo (Cordomi) (1984)	Argentina	Aggregate	1950-80	MPF	41 (inc. ext.)
34. Salmon (1984)	Indonesia	Rice	1965-77	PD(Y)	133
35. da Silva (1984)	Brazil (Sao Paulo)	Aggregate	1970-80	MPF	60-102 (inc. ext.)
36. Doyle & Pidout (1985)	U.K.	Aggregate	1966-80	MPF	30
37. Nagy (1985)	Pakistan	Aggregate	1959-79	MPF	64 (inc. ext.)
38. Ulrich, et al. (1985)	Canada	Melting barley		PD(Y)	51

39. Boyle (1986)	Ireland	Aggregate	1963-83	MPF	26
40. Braha & Tweeten (1986)	USA	Aggregate	1959-82	MPF	47
41. Fox (1986)	USA	Livestock	1944-83	MPF	150
		Crops	1944-83	MPF	180
42. Khan & Akbari (1986)	Pakistan	Aggregate	1955-81	MPF	36
43. Wise (1986)	U.K.	Aggregate	1986	MPF	8-15
44. Evenson (1987)	India	Aggregate	1959-75	PD	100 D,T,S
45. Librero & Perez (1987)	Philippines	Maize	1956-83	MPF	27-48
46. Librero et al. (1987)	Philippines	Sugarcane	1956-83	MPF	51-71
47. Scobie & Eveleons (1987)	New Zealand	Aggregate	1976-84	MPF	30 (inc. ext.)
48. Seldon (1987)	USA	Forestry (products)	1950-80	MPF	163+
49. Seldon & Neuman (1987)	USA	Forestry (products)	1950-86	MPF	236+
50. Sumelius (1987)	Finland	Aggregate	1950-84	MPF (prior R&D)	25-76
51. Tung & Strain (1987)	Canada	Aggregate	1961-80	MPF	high
52. Libraro et al (1988	Philippines	Mango	1956-83	PD(Y)	85-107
53. Russel & Thirtle (1988)	U.K.	Rapeseed	1976-85	PD(Y)	BC = 327
54. Thirtle & Bottomly (1988)	U.K.	Aggregate	1950-81	MPF	70
55. Evenson (1989)	USA	Aggregate	1950-82	MPF (Ext)	43
		Crops	1950-82		45
		Livestock	1950-82		11

56. Riberio (1989)	India	Pearl millet	1987	MFP	57
57. Evenson & McKinsey (1990)	India	Rice	1954-84	MPF (Ext)	65 D,T
58. Librero & Emlane (1990)	Philippines	Poultry	1948-81	MPF	154
59. Pray & Ahmed (1990)	Pakistan	Aggregate	1948-81	MPF	100
60. Byerlee (1990)	Pakistan	Wheat	1965-88	PD	15-20
61. Karanjan (1990)	Kenya	Wheat	1955-88	PD	68
62. Nagy (1991)	Pakistan	Maize	1967-81	PD	19
		Wheat	1967-81	PD	58
63. Azam et al (1991)	Pakistan	Applied research	1956-85	PD	58 (DT)
		Commodity research	1956-85	PD	88 IDT)
		Wheat	1956-85	PD	76 (DT)
		Rice	1956-85	PD	84-89 (DT)
		Maize	1956-85	PD	46 (DT)
		Bajra	1956-85	PD	44 (DT)
		Jowar	1956-85	PD	52 (DT)
		Cotton	1956-85	PD	102 (DT)
Azam et al (1991)	Pakistan	Sugarcase	1956-85	PD	ns (DT)
64. Evenson & McKinsey (1991)	India	Aggregate	1958-83	PD	65
		Wheat	1958-83	PD(Y)	50
		Rice	1958-83	PD(Y)	155

		Maize	1958-83	PD(Y)	94
		Bajra	1958-83	PD(Y)	107
		All cereals	1958-83	PD(Y)	218
65. Dey & Evenson (1991)	Bangladesh	All crops	1973-89	PD	143
		Rice	1973-89	PD(Y)	165
		Wheat	1973-89	PD(Y)	85
		Jute	1973-89	PD(Y)	48
		Potato	1973-89	PD(Y)	129
		Sugarcane	1973-89	PD(Y)	94
		Pulses	1973-89	PD(Y)	25
		Oilseeds	1973-89	PD(Y)	57
66. Iqbal (1991)	Pakistan - Punjab	Rice	1971-88	MFP	42-72
	Pakistan - Sind	Rice	1971-88	MFP	50
	Pakistan - NWFD	Rice	1971-88	MFP	36-11
	Pakistan - Punjab	Cotton	1971-88	MFP	95-102
	Pakistan - Sind	Cotton	1971-88	MFP	49-51
67. Setboonsarg & Evenson (1991)	Thailand	Rice	1967-80	MPF	40 (inc. ext.)
68. Quizon & Evenson (1991	Philippines	Aggregate	1948-84	PFPF	70
		National	1948-84	PFPF	50
		Regional	1948-84	PFPF	100

69. Evenson (1991)	India	Aggregate	1959-75	MPF	72 (inc. ext.)
71. Kumar et al (1992)	India	Cattle	1969-85	MPF	29
72. Evenson (1991)	USA	Applied -crop		D	45
		Applied-livestock		D	11
73. Evenson (1992)	Indonesia	All crops	1971-89	M	212
		Rice	1971-89	D	285
		Maize	1971-89	D	145
		Soybeans	1972-89	D	184
		Mung beans	1971-89	D	158
		Cassova	1971-89	D	ns
		Groundnut	1971-89	D	110
		Extension	1971-89	D	92
74. Pardee et al (1992)	Indonesia	Rice	1968-87	M	55
		Soybeans	1968-87	M	43
75. Fan & Pardee 1992	China	All crops	1965-89	M	20
76. Rosegrant & Evenson (1992)	India	Public research	1956-87	D	67
77. Gollin & Evenson (1992)	IRRI	Rice germplasm	1965-90	DD	high returns
78. Huffman & Evenson (1993)	USA	Applied -crop	1950-85	D	47
		Applied-livestock	1950-85	D	45
79. Evenson et al (1994)	Indonesia	upland rice	1979-92	PD(Y)	100+

		Irrigated rice	1979-82	PD(Y)	100+
		Maize	1979-82	PD(Y)	100+
		Soybeans	1979-82	PD(Y)	10
		Cassova	1979-82	PD(Y)	0
		Groundnut	1979-82	PD(Y)	10
		Sweet Potato	1979-82	PD(Y)	100+
		Mung bean	1979-82	PD(Y)	40
		Cabbage	1979-82	PP(Y)	100+
		Potato	1979-82	PP	100
		Garlic	1979-82	PD(Y)	100+
		Mustard	1979-82	PD(Y)	100+
		Onion	1979-82	PD(Y)	100+
		Shallot	1979-82	PD(Y)	100+
		-----	1979-82	PD(Y)	90
		Rubber	1979-82	PD(Y)	100+
		Oil palm	1979-82	PD(Y)	100+
		Coffee	1979-82	PD(Y)	20-100
		Tea	1979-82	PD(Y)	60-100
		Sugar	1979-82	PD(Y)	50-100
		Orange	1979-82	PD(Y)	80
		Banana	1979-82	PD(Y)	100+
		Papaya	1979-82	PD(Y)	100+
		Mango	1979-82	PD(Y)	0

		Pineapple	1979-82	PD(Y)	100+
		Durian	1979-82	PD(Y)	0
		Meat	1979-82	PD(Y)	0
		Milk	1979-82	PD(Y)	100+
		Eggs	1979-82	PD(Y)	0
80. Avila & Evenson (1995)	Brazil	**State research**			
		Soybeans	1979-92	PD(Y)	40
		Maize	1979-92	PD(Y)	62
		Beans	1979-92	PD(Y)	54
		Rice	1979-92	PD(Y)	46
		Wheat	1979-92	PD(Y)	42
		Federal Reserve			
		Soybean	1979-92	PD(Y)	40
		Maize	1979-92	PD(Y)	58
		Beans	1979-92	PD(Y)	0
		Rice	1979-92	PD(Y)	37
		Wheat	1979-92	PD(Y)	40
81. Alston, et al (1996)	USA	Aggregate		MPF	17-31
82. Chavos & Cox (1997)	USA	Aggregate		MPF	28
83. Van Zyl (1997)	South Africa	Wine grapes		MFP	40
GoPinath & Roe (1996)	USA	Aggregate		CF	37

Table 6: Economic Impact Studies: Pretechnology Science

Study	Country	Period of Study	Production Structure	EMIRR
Evenson (1979)	USA	1927-50	PD	110
		1946-71	PD	45
Huffman & Evenson (1993)	USA	1950-85	PD	crop PTS 57 Lvstk PTS 83 Aggr. PTS 64
Rosegrant, Evenson, Pray	India			
Evenson & Flores	Int.(IRRI)	1966-75	PD	74-100
Evenson (1991)	USA	1950-85	PD	crops 40-59 Lvstk 54-83
Azam et al (1991)	Pakistan	1966-68	PDT	39

Table 7: Economic Impact Studies: Private Sector R&D Spillin

Study	Country/Region	Period of Study	Productive Structure	EWIRR
Rosegrant & Evenson (1992)	India	1956-87	PD	Dom 50+ For 50+
Huffman & Evenson (1993)	USA	1950-85	PD	Crops 41
Ulrick et al. (1985)	Canada		(PE)	Malting barley 35
Evenson (1995)	USA	1950-85	PD	
Gopinat & Roe (1996)	USA	1991	CF	Food processing 7.2 Farm machinery 1.6 Total Social 46.2
Evenson ( )	USA	1950-85		Crop 45-71 Lvstk 81-89

Table 8: Growth Rate Consistency Comparisons
Annual Growth Rates in TFP Required to Support One Percent of Product Investment

	IRR (Percent)			
Time Weights				
	20	40	60	100
1. Extension (1, 1, 1 0 --)	.39 (SR)	.45 (SR)	.50 (SR)	.57 (SR)
2. Extension (1, 1, .1 .5 --)	.39 (SR) .1 (LR)	.45 (SR) .2 (LR)	.50 (SR) .3 (LR)	.57 (SR) .5 (LR)
3. Research (0, .2, .4, .6, .8, 1 --)	.31	.76	1.40	2.80
4. Research (0, .1, .2, .3, .4, .5, .6, .8, .9 1 --)	.42	.87	2.22	5.02

Table 9: Summary IRR Estimates

	Range of IRR								
Programs	**nc**	**ns**	**0-20**	**21-40**	**41-60**	**61-80**	**81-100**	**100+**	**Approx median**
Extension (Farm as unit of obs.)	19		1	1	1	1	2	3	80
Extension (aggregate farm)	5		5	3	2	1	4	8	75
Extension (research combined)	-	-	4	15	8	2	1	3	40
AA Research (PE methods)	2	2	20	44	18	20	12	8	40
AA Research (statistical)		8	12	45	51	29	19	45	50
PTS Research									
Private Sector									
Regions - Extension									
OECD	1		2	6	1	-	2	5	40
Asia	9		9	6	2	1	1	4	35
Latin America	8		1	7	6	1	2	3	44
Africa	6			1			1	1	90
Regions - Research (Applied)									
OECD		3	18	44	28	15	11	22	45
Asia		12	16	17	20	15	10	28	55
Latin America		3	8	21	10	14	5	2	40

Africa			2	2	3	1	1		35
Technological Institutional Levels - Extension									
TI(1)				1			8	2	80
TI(2)			6	9	1	1			25
TI(3)			2	6	5	1	1	3	45
TI(4)			1	3	5	2	6	11	80
Technological Institutional - Research (Applied)									
TI(1)		1	2	8	7	4	2	0	45
TI(2)		1	3	8	14	2	6	9	52
TI(3)		3	21	24	12	24	10	21	55
TI(4)		3	18	44	28	15	11	22	45
Aggregate commodities		1	9	31	21	19	7	5	(44)
Rice			10	14	11	13	5	7	(50)
Wheat			4	9	3	3	2	4	(40)
Maize		1	4	5	2	1	1	6	(40)
All cereals		2	20	34	16	19	9	19	(44)
Oils - legumes		1	3	4	4	5	2	3	(50)
Root crops		1	1	3	3		1	3	(45)
Cotton		1	1	3		2	1	3	(50)
Fruits - vegetables		5	3	6	4	5	2	11	(55)
Sugar		1		4	5	2	1		(50)
Forest products			6	6		1	1	3	(35)
Livestock			3	10	5	4	2	5	(45)
Total			37	67	42	38	19	47	

Table 9: Growth Rate Consistency Comparisons

Annual Growth Rates in TFP Required to Support One Percent of Product Investment

	IRR (Percent)			
Time Weights				
	20	40	60	100
1. Extension (1, 1, 1 0 --)	.39 (SR)	.45 (SR)	.50 (SR)	.57 (SR)
2. Extension (1, 1, .1 .5 --)	.39 (SR) .1 (LR)	.45 (SR) .2 (LR)	.50 (SR) .3 (LR)	.57 (SR) .5 (LR)
3. Research (0, .2, .4, .6, .8, 1 --)	.31	.76	1.40	2.80
4. Research (0, .1, .2, .3, .4, .5, .6, .8, .9 1 --)	.42	.87	2.22	5.02

Table 10: Summary IRR Estimates

	Range of IRR								
Programs	**nc**	**ns**	**0-20**	**21-40**	**41-60**	**61-80**	**81-100**	**100+**	**Approx median**
Extension (Farm as unit of obs.)	19		1	1	1	1	2	3	80
Extension (aggregate farm)	5		5	3	2	1	4	8	75
Extension (research combined)	-	-	4	15	8	2	1	3	40
AA Research (PE methods)	2	2	20	44	18	20	12	8	40
AA Research (statistical)		8	12	45	51	29	19	45	50
PTS Research									
Private Sector									
Regions - Extension									
OECD	1		2	6	1	-	2	5	40
Asia	9		9	6	2	1	1	4	35
Latin America	8		1	7	6	1	2	3	44
Africa	6			1			1	1	90
Regions - Research (Applied)									
OECD		3	18	44	28	15	11	22	45

	Range of IRR								
Programs	**nc**	**ns**	**0-20**	**21-40**	**41-60**	**61-80**	**81-100**	**100+**	**Approx median**
Asia		12	16	17	20	15	10	28	55
Latin America		3	8	21	10	14	5	2	40
Africa			2	2	3	1	1		35
Technological Institutional Levels - Extension									
TI(1)				1			8	2	80
TI(2)			6	9	1	1			25
TI(3)			2	6	5	1	1	3	45
TI(4)			1	3	5	2	6	11	80
Technological Institutional - Research (Applied)									
TI(1)		1	2	8	7	4	2	0	45
TI(2)		1	3	8	14	2	6	9	52
TI(3)		3	21	24	12	24	10	21	55
TI(4)		3	18	44	28	15	11	22	45
Aggregate commodities		1	9	31	21	19	7	5	(44)
Rice			10	14	11	13	5	7	(50)
Wheat			4	9	3	3	2	4	(40)
Maize		1	4	5	2	1	1	6	(40)
All cereals		2	20	34	16	19	9	19	(44)
Oils - legumes		1	3	4	4	5	2	3	(50)
Root crops		1	1	3	3		1	3	(45)
Cotton		1	1	3		2	1	3	(50)
Fruits - vegetables		5	3	6	4	5	2	11	(55)
Sugar		1		4	5	2	1		(50)
Forest products			6	6		1	1	3	(35)
Livestock			3	10	5	4	2	5	(45)
Total			37	67	42	38	19	47	

Table 11: IPR Summary

	Studies	Number of IRRs Reported	Percent Distribution					
			0-20	21-40	41-60	61-80	81-100	100+
Extension								
Farm Observations		16	.56	0	.06	.06	.25	.06
Aggregate Observations		29	.24	.14	.07	0	.27	.27
Combined Research and Extension		36	.14	.42	.28	.03	.08	.06
By Region								
OECD		19	.11	.31	.16	0	.11	.16
Asia		21	.24	.19	.19	.14	.09	.14
Latin America		23	.13	.26	.34	.08	.08	.09
Africa		10	.40	.30	.20	.10	0	0
All Extension		81	.26	.23	.16	.03	.19	.13
Applied Research								
Project Evaluation		121	.25	.31	.14	.18	.06	.07
Statistical		254	.14	.20	.23	.12	.10	.20
Aggregate Programs		126	.16	.27	.29	.10	.09	.09
Commodity Programs								
Wheat		30	.30	.13	.17	.10	.13	.17
Rice		48	.08	.23	.19	.27	.08	.14
Maize		25	.12	.28	.12	.16	.08	.24
Other Cereals		27	.26	.15	.30	.11	.07	.11
Fruits and Vegetables		34	.18	.18	.09	.15	.09	.32
All Crops		207	.19	.19	.14	.16	.10	.21
Forest Products		13	.23	.31	.68	.16	0	.23
Livestock		32	.21	.31	.25	.09	.03	.09
By Region								
OECD		146	.15	.35	.21	.10	.07	.11
Asia		120	.08	.18	.21	.15	.11	.26
Latin America		80	.15	.29	.29	.15	.07	.06
Africa		44	.27	.27	.18	.11	.11	.05
All Applied Research		375	.18	.23	.20	.14	.08	.16
Pre-Technology Science		12	0	.17	.33	.17	.17	.17
Private Sector R&D		11	.18	.09	.45	.09	.18	0
Ex Ante Research		83	.11	.36	.16	.07	.01	.05