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REVIEW OF METHODS USED TO EVALUATE RETURNS TO AGRICULTURAL RESEARCH

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1. INTRODUCTION

World expenditures on agricultural research have increased substantially
over the past twenty five years. As public investment in agricultural research
has continued to expand, attention has focused increasingly on the productivity
of this investment and the efficiency with which funds are allocated.
Government decision makers desire information on the payoff of agricultural
research since it competes with alternative uses for public funds. Research
administrators desire information on the expected payoff from funds allocated
to alternative research investments. And, the general public has become
increasingly concerned with the productivity of their tax dollars.

The need for public support of agricultural research arises in part,
because much of the knowledge generated by research is a public good once it
is produced. Private firms tend to underinvest in many types of agricultural
research from society's point of view because they cannot internalize many
of the benefits of that research. The lack of a market pricing system for
research output means that public decision makers also may allocate too few
or too many resources to research either in the aggregate or to individual
areas.

Several approaches have been employed over the past 25 years to evaluate
the returns to agricultural research. Some have provided estimates of the
returns to aggregate agricultural research, others have provided methods

for ranking different research projects or problem areas, this ranking being based on other factors as well as economic returns. With a few exceptions, most of the methods have not required elicitation of the appropriate decision makers' preferences. A diversity of approaches have been employed because different questions have been examined, new methodologies have been developed, and differing amounts of resources have been available to conduct this "research on research."

The purpose of this paper is to review the major research evaluation techniques which have been used. This review benefits greatly from previous reviews in this area. Peterson (1971) examined techniques and results of studies which measured returns to agricultural research in the United States. Shumway (1973, 1977) concentrated on project ranking methods and included several techniques which have been applied in evaluating nonagricultural research. Schuh and Tollini (1977) at the request of the Consultive Group For International Agricultural Research (CIGIAR) reviewed methods and procedures which might be applied to CIGIAR programs and activities. More recently Sim and Gardner (1978) examined several of the main techniques and results.

The review by Schuh and Tollini provides an excellent summary of the major issues involved in agricultural research evaluation and contains broader coverage than the other reviews. The present study follows their procedure of categorizing returns to research studies into ex ante and ex post evaluation. It attempts, however, to be more comprehensive in terms of the number and types of studies reviewed. At the same time it will not include methods used exclusively for evaluating nonagricultural research. Major studies which illustrate each technique are discussed and compared. An additional list of uncited references is included to which interested readers can turn for other examples of the techniques described.

It is hoped that this review will provide the reader with insights into (1) differences in assumptions made in studies using similar methods, (2) which techniques might be appropriate to answer different questions, and (3) in what areas the methodology needs development or improvement.

2. EX POST EVALUATIONS

Studies which have made ex post evaluations of agricultural research can be classified into two major groups: (1) those which explicitly or implicitly use the concepts of consumers and producers surplus and in general estimate an average rate of return to research, and (2) those which include research as a variable in a production function and estimate a marginal rate of return for research.[1] In addition there are two major studies which defy the two classes mentioned above. One of them estimates the impact of technology on national income and the other measures the nutritional impact of agricultural research.

2.1 Consumer and Producer Surplus Approach [2] [3]

The first major attempt at quantitative evaluation of agricultural research investments was conducted by Schultz (1953, pp. 117-122) who calculated the value of inputs saved in agriculture because of improved, more efficient production techniques and compared this with the cost of research and development.

1/ The production function approach in fact also implicitly uses consumer and producer surplus with simplifying assumptions about the demand elasticity and the form of the supply function. These approaches are different enough, however, that it makes sense to treat them separately.

2/ An excellent discussion of consumer and producer surplus and their shortcomings can be found in Currie, Murphy and Schmitz (1971) and a more abbreviated but very coherent explanation can be found in Hertford and Schmitz (1977).

3/ This approach has also been called the Index Number approach.

As a lower limit Schultz estimated that the output per unit of input
was 32 percent higher in 1950 than in 1910. Thus to have produced 1950
output with 1910 techniques would have required $9.6 billion more of inputs
that the $30 billion actually used (using 1910-14 price weights). He also
derived an upper limit by using 1946-48 price weights. In effect he calculated
the increase in consumer surplus resulting from the savings in inputs
(Figure 1). The area under the supply curve S_1 to the left of the demand
curve D_1 represents the total cost of producing 1950 output with 1950
techniques. The area between S_1 and S_2 to the left of D_1, represents the
additional resources required to produce that output with 1910 techniques.
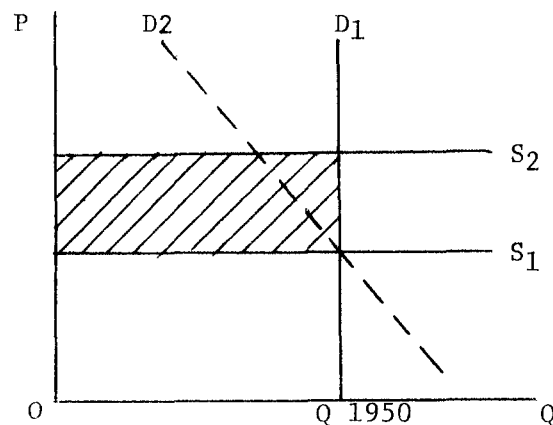
Figure 1

Schultz pointed out that a downward bias in research returns resulted
from this estimation technique because all public research and extension
expenditures were not aimed at producing and distributing new techniques.
At the same time an upward bias was introduced because the role of private
research was neglected. Peterson (1971) pointed out that an additional
downward bias resulted from the fact that production levels actually would
have declined without research and development. A fourth bias resulted from
the implied perfectly inelastic demand curve. A more elastic demand curve
such as D_2 would have reduced the benefits.[4]

4/ It could be argued, however, that the demand for agricultural products is
    quite inelastic in the aggregate so this bias was small.

Schultz estimated the return to agricultural research at the aggregate level. Working at the commodity level Griliches (1958) calculated the loss in consumer surplus that would occur if hybrid corn were to disappear. His analysis assumed that the adoption of hybrid corn shifted the supply curve of the product downward and to the right. He estimated the returns for the two polar cases of perfectly elastic (Figure 2) and perfectly inelastic (Figure 3) supplies. He assumed the demand elasticity was minus one.
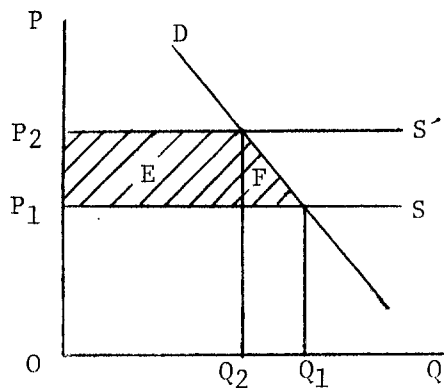
Figure 2
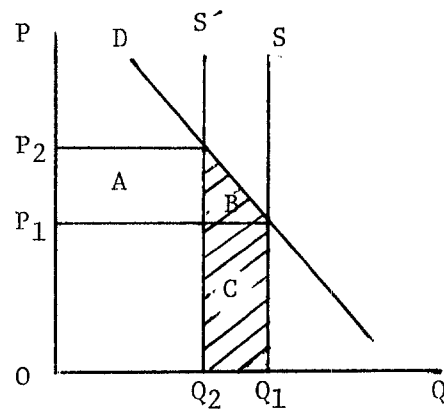
Figure 3

In figure 2 consumer surplus equals E + F which equals $K \, P_1 \, Q_1$ $(1 - \frac{1}{2} Kn)$ where $K = \frac{\Delta P}{P_1}$ and n is the demand elasticity. In figure 3

consumer surplus = A + B, producer surplus equals -A + C and the net surplus equals $A + B - A + C = B + C = K \, P_1 \, Q_1 \, (1 + \frac{1}{2} \frac{K}{n})$ where $K = \frac{\Delta Q}{Q_1}$ and n is

the demand elasticity. His approach has the advantage of simplicity as he does not have to calculate either demand or supply elasticities.

Peterson (1967) generalized Griliches formula for estimating consumer surplus and applied it to poultry. He calculated the case where supply is neither perfectly elastic nor perfectly inelastic (figure 4) and did not require a demand elasticity of minus one as Griliches' formulae did.

Figure 4
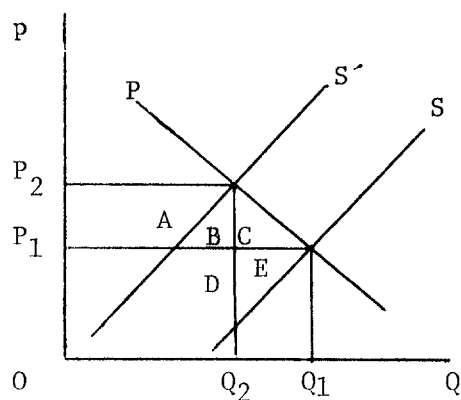
Peterson's gain in net surplus = A + B + C + (-A + E + D) = D + B + C + E.
He provided a formula for approximating this area and calculated the benefits.
He then compared these benefits with the costs of research and extension
and calculated an internal rate of return.

Schmitz and Seckler (1970) extended the model to take account of
resources which were released (in their example labor) with the introduction
of the mechanical tomato harvester. They estimated benefits by the "value
of inputs saved" as Schultz did and then estimated the hours of labor lost,
multiplied this by the wage rate and subtracted it from benefits to get a
form of net benefits.5/ This approach assumed that freed up labor was then
unemployed and received no compensation. In addition they calculated the
net social rate of return assuming alternative levels of compensation for
the displaced farm workers.

Ayer and Schuh (1972) altered the model to incorporate a cobweb
behavorial assumption for cotton production in Brazil (figure 5).

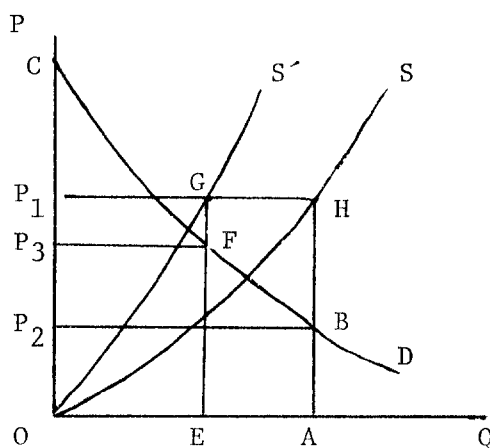
Figure 5

5/ Grossfield and Heath (1966) had used the value of inputs saved approach
   to calculate the benefits from publicly supported research on a potato
   harvester. They suggested the need to adjust the benefits for displaced
   labor but did not do so in their study.

Social returns equal (OABC - OAH) - (OEFC - OEG) in figure 5 where

S equals supply of cotton fiber when improved varieties are planted, S´

equals supply of cotton fiber when unimproved varieties are planted, and D is

the demand for cotton fiber. The supply of cotton was postulated to depend

on the previous year's price. S´ is shifted K percent to the left of S where

K is determined by the difference in fiber yield between the old and improved

varieties and the proportion of each new variety planted. They estimated

the demand and supply equations and collapsed them into two dimensions so that

D could be represented by $P = nQ^{\alpha}$, S could be represented by $Q = mP_{t-1}^{\beta}$,

and S´ could be represented by $Q = (1 - K) mP_{t-1}^{\beta}$. Where:

> h = all parameters and variables influencing demand but excluded from the
> equation.

> m = all parameters and variables influencing supply but excluded from the
> equation.

Net social returns were then estimated for each year as follows: Social

returns = $\int_{o}^{A}$ (D) d (Q) - $\int_{o}^{A}$ (S) d (Q) - $\int_{o}^{E}$ (D) d (Q) + $\int_{o}^{E}$ (S´) d (Q).

They then compared these returns with the estimated costs of research and

development and calaculated the internal rate of return. Elasticity estimates

and K values were varied to test the sensitivity of their results and the

distribution of benefits between producers and consumers were examined.[6]

The authors stressed that their estimates were dependent on elasticities,

trade volumes and other economic policies. Finally, they made a qualitative

analysis of which factor owners received the benefits of the technical

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6/ The change in producer surplus = $OABP_2$ - OAH

The change in consumer surplus = $P_2BC - P_3FC = P_2BFP_3$

change by looking at characteristics of demand and supply for the
individual input categories.

Akino and Hayami (1975) used a similar approach (but without the
cobweb specification) to estimate the social benefits from plant breeding
research in Japan. They also looked at the distributional effects of this
research and at the effects of government rice import policies. In figure
6 the actual demand and supply curves are represented by D and S while S´
represents the supply curve that would have existed in the absence of the
improved varieties.
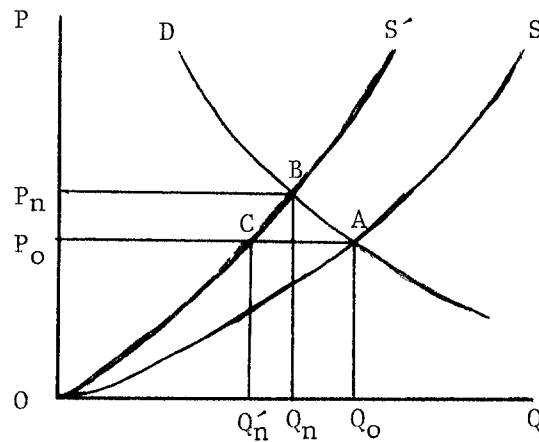
Figure 6

Assuming market equilibrium and no rice imports the increase in consumer
surplus equals the area P_n B C P_o plus the area ABC. The increase in
producer surplus equals the area AOC minus the area P_n B C P_o and net surplus
equals ABO. If, on the other hand, the government decided to keep the price
of rice at P_o the total surplus gain would be an increase in producer surplus
of AOC. Without the increased production due to research, Japan would have had
to import ACQ_nQ_o to keep the price at P_o. Therefore this area represents a

gain in foreign exchange due to the research. Akino and Hayami provided a formula for estimating P_n B C P_o, ABC, AOC, and Ac Q_n Q_o.

Scobie and Posada (1978) employed the consumer-producer surplus approach in their sutdy of the impact of technical change in rice production in Colombia. They considered the incidence of research costs among upland producers, irrigated producers, and consumers and subtracted this from the gross benefits for each group. They distributed the net benefits across income groups of dryland producers, irrigated producers, and consumers. They concluded in their case that consumers benefited the most, producers suffered losses, but small producers lost the most.

Several other studies have used this consumer-producer surplus approach including Evenson (1969) for sugar cane in South Africa; Barletta (1970) for corn and wheat in Mexico; Hines (1972) for corn in Peru; Hertford, Ardila, Rocha, and Trujillo (1977) for rice, soybeans, wheat and cotton in Colombia; Nagy and Furtan (1978) for rapeseed in Canada, and others.

Lindner and Jarrett (1978) have pointed out the importance of recognizing that the total level of annual social benefits from the adoption of an innovation is influenced by the nature of the shift in the supply curve. They hypothesized that certain types of innovations such as biological and chemical innovations are more likely to generate a divergent supply shift (figures 7 and 8) while mechanical or organizational innovations will be more likely to generate a convergent shift (figure 9). A parallel shift is shown in figure 10. They based their reasoning on the effects of different types of innovations on the average costs of marginal and inframarginal firms in the industry and the location of those firms on the supply curve.[7]

7/ Lindner and Jarret use the term inframarginal to refer to the more profitable, lower average cost firms.
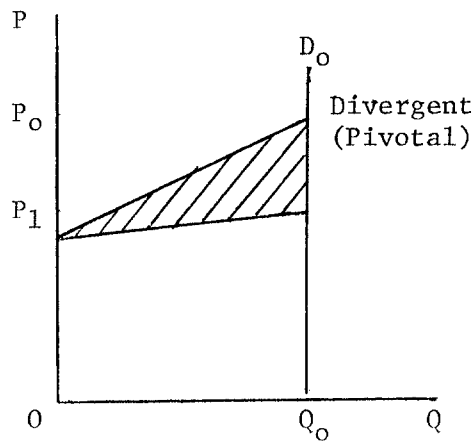
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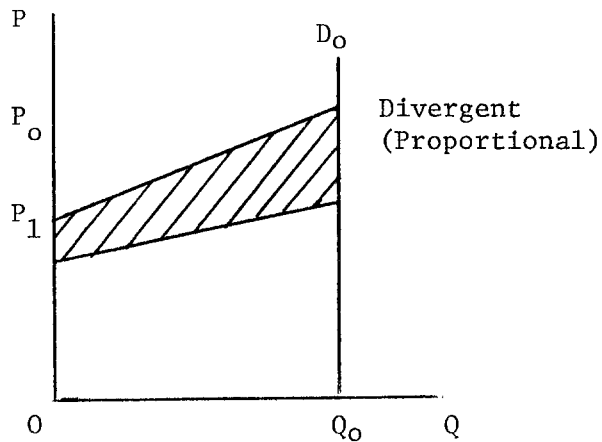
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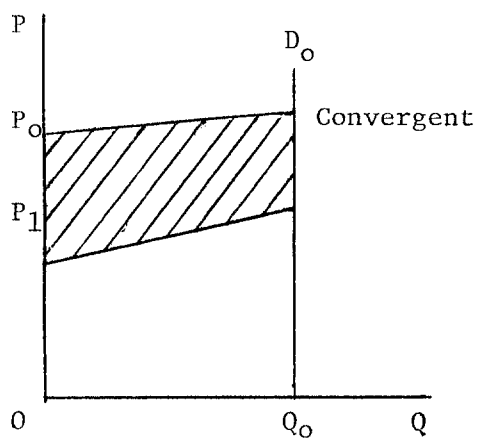
Figure 9
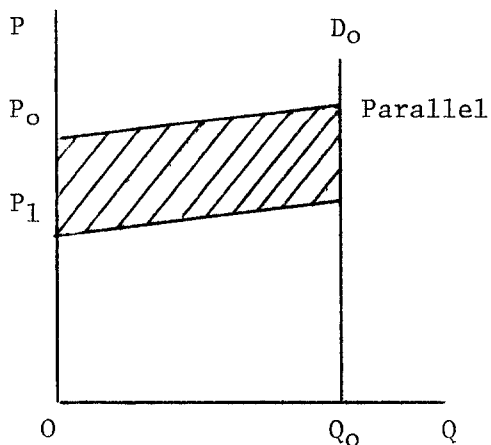
Figure 10

Lindner and Jarrett also provided a generalized formula for measuring research benefits which avoids some of the biases which can arise from assumptions about supply shifts and elasticities. Utilizing figure 11,

Total benefits $(A_1 \, M_1 \, M_o \, A_o) = 1/2 \, (P_o \, Q_1 - P_1 \, Q_o + Q_o \, A_o - Q_1 \, A_1)$

Producer benefits $= 1/2 \, (Q_o \, A_o - Q_1 \, A_1 - P_o \, Q_o + P_1 \, Q_1)$

Consumer benefits $= 1/2 \, (P_o \, Q_1 - P_1 \, Q_o + P_o \, Q_o - P_1 \, Q_1)$
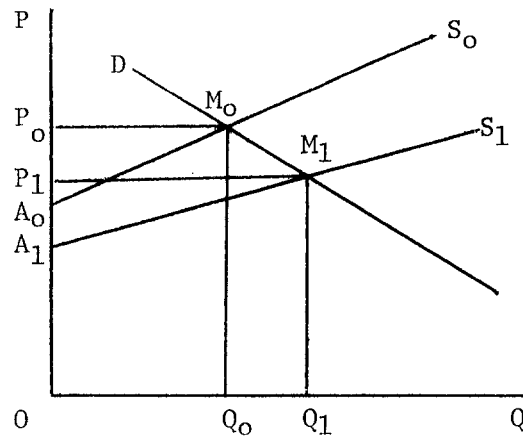
Figure 11

While it is difficult to measure some of the variables in their

formulation, their point about biases arising from differing assumptions

about supply shifts and elasticities is well taken. Scobie (1978)

drew attention to different results which could be obtained by different

formulae found in the literature. Sarhangi et al. (1977) describe the

effects of using (1) different specifications of the initial supply and

demand functions, (2) different assumptions about the nature of the shift

of the supply functions, and (3) point versus arc elasticities in

calculating producers' and consumers' gains.

Before concluding this section, two other types of studies which

fall into the consumer-producer surplus classification should be mentioned.

The first is a study by Duncan (1972a, b). Duncan estimated the benefits

of research which increases the productivity of a product which, in turn,

is an input into the production of another commodity (i.e. the demand for

the product is a derived demand). He used the example of research leading

to new pasture technologies. The increase in productivity shifts the

demand curve for the input ID_1 to ID_2 in figure 12.
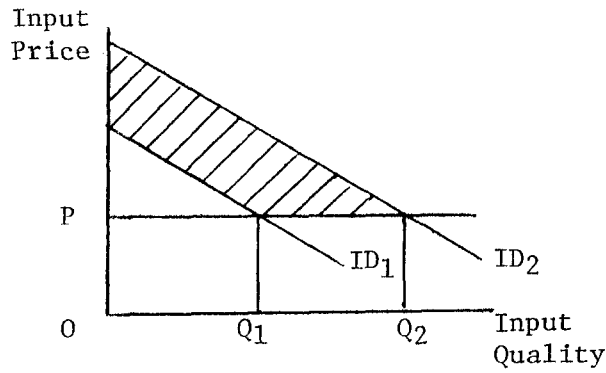
Figure 12

Under certain assumptions the hatched area then represents the gross welfare gain from the increase in productivity. He presented a formula for calculating this area for certain new technologies and calculated the internal rates of return on the costs associated with the projects generating the new technologies. Finally, he assumed a perfectly elastic demand curve for the final product which implies that the indicated welfare gain accrues to producers.

The second type of studies are those ex post benefit cost analyses which have measured net benefits by estimating the increase in production and valuing this at a price which is taken as given (Tosterud et al., 1973; and Kislev and Hoffman 1978). These studies explicitly or implicitly have assumed the existence of a perfectly elastic demand curve and vertical supply curve (figure 13).
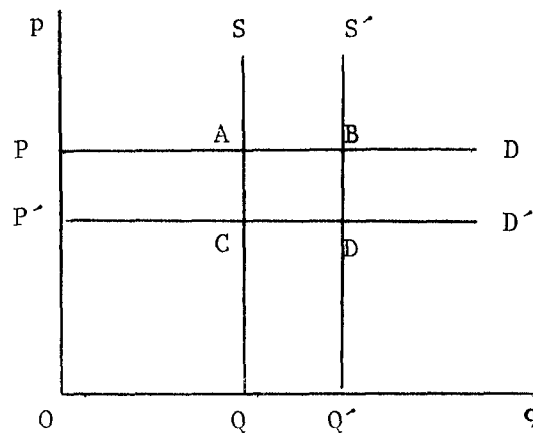
Figure 13

Tosterud *et al.* calculated ex post benefit-cost ratios for research
on Target rapeseed and Selkirk wheat in Canada. They compared yields
with the next best varieties and estimated the benefits for Canada, the
U.S. and the two countries together. Their measure of the benefits can
be represented by A B Q´ Q in figure 13. They recognized that there had
been a price effect due to elasticity in the actual demand curves.
Consequently they estimated how much the price would have dropped with
different assumptions about the demand elasticity and recalculated the
benefits as the area CDQ´ Q.

Kislev and Hoffman estimated returns to research on wheat in Israel.
Since Israel imports most of its grain they assume that agriculture faces
a completely elastic demand curve for wheat and the economic contribution
of the additional output can, therefore, be evaluated at the world price
of wheat. They use yield regressions to determine the yield increases
due to new varieties, multiply those increases by the area sown, and then
multiply by the world price. They, in effect, estimate the area A B Q´ Q
in figure 13.

The discussion in this section illustrates the extent to which
studies employing the consumer-producer surplus approach have differed
in their specification of supply and demand functions and in the nature
of the supply function shifts. This is not to say that one specification
is superior to another since this depends on the situation being modeled.
It is important, however, to recognize the assumptions implicit in a
particular specification. With regard to the nature of the supply shift it
is useful to regard yield increasing or preserving research as shifting
the supply curve horizontally and cost reducing research as shifting it

vertically. The Industries Assistance Commission (IAC) report (1976), for example, measures sheep blowfly research in terms of a production effect while it measures research on tick resistant cattle in terms of a production cost reducing effect. The former can be thought of as shifting the supply curve horizontally (figure 14) while the latter as shifting it vertically (figure 15).
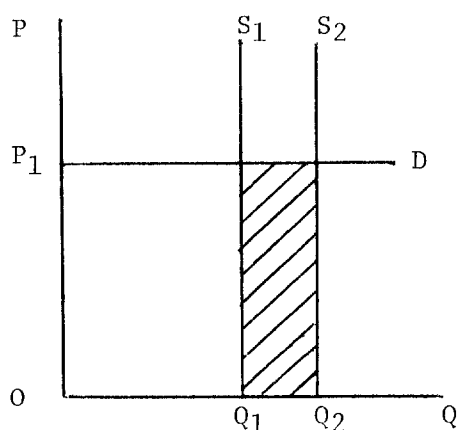
Figure 14
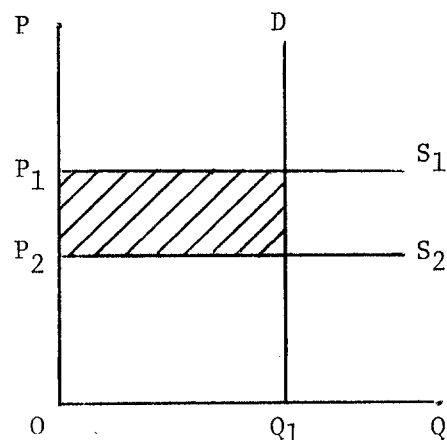
Figure 15

2.2 Production Function Approach

The second major approach used to measure the returns to agricultural research is the production function approach. The basic model used by this approach has been:

$$Q = A \prod_{i=1}^{m} X_i^{\beta_i} \prod_{j=0}^{n} R_{t-j}^{\alpha_{t-j}} e^u \quad \ldots \ldots \ldots \ldots \ldots \quad (1)$$

Where:

Q = value of agricultural output

A = shift factor

X_i = i^{th} conventional production imput

R_{t-j} = expenditures on research (and extension) in years t to t-j.

β_i = the production coefficient of the ith conventional input.

α_{t-j} = the partial production coefficient of research (and extension) in the $t-j^{th}$ year.

u   = random error term.

The major source of variation between studies using a model similar to equation (1) has been in the specification of the length and shape of the lag in the impact of research on output. Early studies, such as the pioneering work by Griliches (1964), used either a single year's expenditure or a simple average of two years. However, more recent studies, for example, Evenson (1967, 1968), Fishelson (1968), and Cline (1975) have developed theoretical reasoning and presented some empirical evidence which lend weight to the use of an inverted 'V' or 'U' shaped distribution. These studies have also attempted to empirically determine the appropriate length of this lag. For example, for the U.S. the concensus suggests a mean lag of 6 to 7 years.

Cross-section data have mainly been used in the estimation of the type of model described in equation (1). Some studies have used the aggregate level of output as their unit of study, for example, see Griliches (1964) for the U.S. and Kahlon et. al. (1977) for India, while others have applied the model to different commodity groups, see for example, Peterson (1966, 1967) and Bredahl (1975). The latter study in addition to estimating the mean marginal internal rate of return (MIRR) to each of the four commodity groups, (that is, cash crops, dairy, poultry and livestock) also discussed the possibility of increasing the overall rate of return by reallocating some of the research resources from the low to the relatively high rate

of return commodity groups in different states (see also Bredahl and Peterson (1976)).

Studies using time series data have adopted an alternative model specification to equation (1). Instead they have used:

$$P = A \ W^{\gamma} \ E^{\varepsilon} \ \prod_{j=0}^{n} \ R_{t-j}^{\alpha_{t-j}} \ e^{u} \qquad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \qquad (2)$$

where:

P = a productivity index of agricultural output

W = weather index

E = measure of the education level of farm workers

γ, ε = productivity coefficients for the associated inputs.

Not all, but the majority of studies have used a Cobb-Douglas specification for this productivity function. The high correlation problems associated with time series data for conventional production inputs and, more importantly, the general lack of sufficient time series data for all of the important conventional inputs are the main reasons that time series studies have adopted this type of model.

Evenson (1967, 1968) first used this type of model to calculate the marginal product of research in the U.S.. Cline (1975) (see also Lu and Cline (1975)) updated and refined Evenson's work for U.S. aggregate agricultural output and the ten USDA production regions.

The quality of the productivity indices used by these studies is one of their critical aspects. Evenson (1978) summarized some recent comprehensive work on these indices for the U.S.. He presented alternatives to the officially published series of the U.S. aggregate index for 1870 to 1971, regional indices for 1927 to 1971 and also individual state indices

for 1949 to 1971. Evenson then used these to examine the relationship between productivity and investment in agricultural invention, education, and research and extension separately. Due to the unavailability of data for all variables, different specifications of equation (2) were used to analyze the three time periods 1868-1925, 1927-1950, and 1948-1971. A particularly important aspect of the analysis of the most recent time period was the attempt to isolate the spillover effect of research between different states. To facilitate this part of the study he divided the U.S. into geoclimatic regions which did not necessarily coincide with state boundaries. The research expenditure applicable to each region was then determined using commodity group research expenditure and output value proportions. His results showed a significant spillover effect of agricultural research between states.

While all of the studies discussed above using models based on either equation (1) or equation (2) have used research (and extension) expenditure levels as their measure of research, there has been considerable variability in the items actually included in this expenditure figure. For example, in U.S. studies the range has been from Bredahl (1975) who used only commodity specific research expenditure by the state experiment stations to Cline (1975) who used total research for commodity and noncommodity areas by experiment stations, USDA expenditure, extension expenditure, and soil conservation service expenditure. Alternatively, though, studies by, for example, Evenson and Kislev (1973, 1975) and Evenson (1974) used the number of scientific publications in particular agricultural sciences as a proxy for research. They estimated functions for various countries and attempted to estimate the spillover effect of one country borrowing

research from another in a region. Evenson (1974) also separated research into commodity specific applied research and noncommodity specific agriculturally related basic research. Evenson and Binswanger (1978) included separate variables to measure the effects of applied technically oriented research and supporting or basic science oriented research.

The final aspect of the production function approach to be discussed here is the calculation of the marginal internal rate of return (MIRR). As recently summarized by Davis(1979), expost studies have used a range of estimation procedures. The main source of these differences stems from the form in which the research production coefficients have been estimated. A few studies, for example, Cline (1975) have attempted to estimate the individual partial production coefficents, α_{t-j}. The majority of studies however, have in fact only estimated the total production coefficient $\alpha = \sum_{j=0}^{m} \alpha_{t-j}$. For these studies the resultant issue has then become; how is the total marginal product of research, that is,

$$MPR = \alpha \frac{Q}{R}$$

distributed through time?   The assumptions used to answer this question   have resulted in the observed variability. Davis showed that the MIRR estimates are very sensitive to the various procedures that have been used and concluded that this should be kept in mind when estimating a MIRR but particularly when comparing the MIRR's from different studies.

The production function approach has proven to be a useful means of isolating the different influences on agricultural production. The effect of research in one area can be separated from education, conventional inputs or from research in another geographical area. Perhaps the major limitations are the data requirements and the uncertainty involved with projecting past rates of return into the future.

2.3 Change in National Income Approach

Tweeten and Hines (1975) employ a different approach in their study
of the returns to aggregate agricultural research. They calculate how
much lower the national income would be if the percentage of people on
farms was still the same as in 1910 and the resulting additional farmers
had the income of today's farmers instead of today's nonfarmers. They
estimate the costs of public and private research, education, and federal
programs and then calculate a benefit-cost ratio.

The larger the gap in earnings between farm and nonfarm workers and
the higher the rate of migration off the farm the higher the returns to
agricultural research and extension as measured by this procedure. The
incremental returns to research approach zero as the farm population
approaches an equilibrium size.

2.4 Nutritional Impact Approach

Pinstrup-Anderson, Londoño, and Hoover (1976) have developed a
procedure to estimate the nutritional impact of alternative commodity
priorities in agricultural research and policy. The model estimates
the distribution of supply increases (of commodities) among consumer
groups, the related adjustments in total food consumption, and
implications for calorie and protein nutrition.

Their model has two parts, the first involves estimating a price
elasticity of demand matrix for each of a number of income strata and
for the market as a whole, and the second deals with the distribution of
a hypothetical supply increase of any one good among these income strata,
the resulting adjustments in consumption of all other goods, and the
impact on calorie and protein nutrition.

The model requires data on prices, incomes, and quantities of food consumed by households. It only looks at the nutrition goal and is not concerned specifically with rates of return or with distribution of benefits among producers and consumers.

3. EX ANTE EVALUATIONS

A number of different approaches have been used for ex ante evaluation of agricultural research. This diversity is partly the result of different studies trying to answer different questions and partly due to differences in the way that uncertainty about the future has been handled. For purposes of discussion these studies can be classified into four groups: (1) those which have made use of scoring models to rank research activities, (2) those which have employed benefit cost analysis to establish rates of return to research, (3) those which have used simulation models, and (4) those which have used mathematical programming to help select an optimal mix of research activities.

3.1 Scoring Models

In 1966 the National Association of State Universities and Land Grant Colleges - U.S. Department of Agriculture (NASULGC-USDA) published the results of a study of agricultural and forestry research programs in the U.S. [8] A task force evaluated the strengths and weaknesses in the research program, identified future research problems and recommended a level of public research for the next few years. A major result of this study was the systematic classicication of research areas which

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[8] USDA (1966). Williamson (1971) provides a good summary and evaluation of the report and the procedures used.

is now used in the Current Research Information System (CRIS) of the USDA. A simple scoring model was used to determine the extent to which each research problem area met certain criteria. Each specified criterion was given a numerical weight in terms of importance. While this system was used to evaluate research projects it was not employed as a mathematical basis for allocating resources.

Mahlstede (1971) and Paulson and Kaldor (1968) have reported on a scoring model which was set up at Iowa State University. The purpose of the model was "to ensure the greatest return for the research money spent at the experiment station" (Mahlstede, p. 327). It was also hoped that use of the scoring model would facilitate the acquisition of additional funds.

The steps followed were to first get all the administration and department heads together to set goals. They decided on the goals of growth, equity, and security. Then the research was divided into three major areas: commodity research, resource research, and agricultural management research. These areas were divided into 19 sub-areas and a panel assigned to each. The panels were asked to identify research alternatives within each area and to estimate the costs of such research. Finally a scoring procedure was used based on ten criteria. Consideration was given to the probability of success. "The validity of the study rests heavily on the premise that scientists, through a systematic group effort, can predict, to some degree, the outcome of scientific inquiry and, thus, improve the basis for selecting research activities that will offer the highest return" (Mahlstede, p. 327).

Shumway and McCracken (1975) reported on a model used at the North Carolina Agricultural Experiment Station to determine how much emphasis should be placed on each of the research problem areas (RPA's) as defined by the CRIS classification of the USDA. "The key actors in the study included the experiment station administration, two department head committees concerned with research planning and program implementation, twenty interdisciplinary faculty task forces, eighteen extramural scientist panels, and twenty three academic departments" (Shumway and McCraken, p. 714).

The procedure used can be briefly summarized by saying that each of the last three groups of people either rated or scored problem areas or recommendations or recommendations of other groups. A simple scoring model was used as well as a Delphi procedure.

Shumway and McCracken noted that there was little consistency within or among groups of scorers. Less attention was given to setting goals than was done with the Iowa model.

The NASULGC-USDA, Iowa,and North Carolina scoring models are all conceptually simple but labor intensive. They require frequent meetings of a large number of people for whom the opportunity cost of time is high. They do have the advantage of incorporating benefits which are difficult to quantify by most other procedures.

3.2   Ex Ante Benefit-Cost Approach.

Several studies have evaluated returns to proposed agricultural research by calculating rates of return or benefit-cost ratios. These studies are conceptually analogous to the consumer-producer surplus studies described

previously in the ex post section. Because yield increases or cost reductions were projected rather than observed, one of the major differences among them is the manner in which these projections were obtained.

Fishel (1971) described a computerized model for collecting and processing information needed to evaluate research activities and to select an efficient allocation of resources. The model, called MARRIS,[9] involved three major steps: specification, estimation, and analysis. Selection was left to the decisionmaker. Basic estimation involved calculating benefit-cost ratios, benefits minus costs, and internal rates of return. To obtain the information needed, surveys were sent to several scientists in the field of study related to the proposed research project. They estimated average annual expenditures, time requirements, and technical feasibility. Subjective probability distributions of costs and values were generated for alternative levels of annual expenditures by a Monte Carlo sampling procedure. MARRIS is one of the most logically thought out and sophisticated research evaluation models yet developed. Its complexity may lead to a somewhat higher user cost in terms of time and effort than simpler models. This may be one reason why it has not received more widespread use.

Ramalho de Castro and Schuh (1977) presented a model which focused on the growth and distributional effects of technical change as well as the direct and indirect effects of research. They set four goals for the research program. They assumed a shift in the supply curve due to technological change for various crops and compared distributional effects on consumers and producers which resulted from the demand and supply elasticities. They looked at trends in factor scarcity and other implications

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[9] Minnesota Agricultural Research Resource Allocation Information System.

for the direction which research should take. They discussed the effects of technological change in the agricultural sector on the non-agricultural sector and the effect of economic policies on the social benefits and costs of research programs. They relied primarily on several types of secondary data to estimate the effect of research on different crops and did not utilize scientist's estimates of yield increases, adoption rates, or probabilities of success. This was probably because their focus was on distributional effects of research and not on the rates of return. It also minimized the burden on scientists.

Taking a somewhat different approach Easter and Norton (1977) used estimates provided by scientists on the yield and cost effects of certain research lines and on the expected adoption rates of new technologies and then applied benefit cost analysis to the Land Grant Universities 1978 USDA budget requests for soybean and corn production research. A 10 percent discount rate was applied, harvested acreage was held constant, and a specific set of prices was assumed.

An important aspect of the analysis was the sensitivity of the benefit cost ratios to variations in the probabilities of success, the expected yield increases, the product prices, and the length of the lags between research expenditures and the availability of the results to the farmers. These results provide decision makers with information on the relative importance of added precision in the estimation of the variables involved in the evaluation.

Effects on the prices received by farmers, meat prices, and the prices of fats and oils were estimated by making use of impact multipliers from another study. The effects on consumer surplus and gross farm income were then estimated.

Araji, Sim, and Gardner (1971) carried out a similar type of analysis to evaluate research and extension programs on sheep, fruits and vegetables, potatoes, cotton, and rice for 1977 in the western region of the U.S. Personal interviews were conducted with agricultural researchers and extension specialists to determine initiation and termination dates for research projects, the probability of research success, the probability and rate of adoption of research results with and without extension, and the resources required to implement and maintain the new technology. The yield, quality, and cost of production changes resulting from the new technology were estimated, as were the flow of benefits and costs, the benefit cost ratios, and the internal rates of return for each research project. The authors also estimated the reduction in productivity which would result from eliminating maintenance research and they used flexibility ratios derived from demand elasticities to determine the effects on prices and consumer expenditures for the commodities.

In a study which attempted to measure the secondary impacts of an increase in agricultural productivity on other sectors of the U.S. economy, Eddleman (1977, p. 34-35) made use of the multipliers from a national input-output analysis. Gross benefits were measured as changes in other sectors' output and net benefits as net wage increases resulting from expanded employment in each of the sectors and as net profit gains in each of the sectors.

The key to ex ante benefit cost analysis is the cooperation between physical and social scientists. If that cooperation is present, rates and distribtions of returns can be assessed relatively quickly. As in the case with ex post benefit-cost analyses, assumptions made with respect to demand and supply elasticities should be kept in mind.

3.3 <u>Simulation Approach.</u>

A number of researchers have constructed simulation models for agricultural research evaluation. Simulation lends itself to a wide range of structures as illustrated by the models described here. It should be noted that the MARRIS model described in the last section could appropriately have been included in this section as well.

Pinstrup-Anderson and Franklin (1976) describe the basic components of a simulation model to assist in predicting the relative contributions and costs of alternative research activities in order to establish priorities and allocate research resources.

They indicate that the first step required is to establish overall goals. This is followed by (2) an identification of changes in product supply, input demand, and farm consumption necessary to achieve those goals, (3) identification of research problems and (4) identification of alternative technologies to solve the problems. The fifth step is to estimate the time, costs, and probabilities involved in research and farm adoption of the alternative technologies. Sixth is the estimation of effects of alternatives on farm consumption, product demand, and input-supply. Seventh and finally, it is necessary to specify the technology to be developed and the scientists'working objectives.

Many of the steps require a fairly extensive amount of data and a number of mathematical relationships must be estimated. The model was suggested for use by the international research centers.

Lu, Quance, and Liu (1978) examined the relationship between research and extension (R & E) and agricultural productivity growth by formulating a simulation model including R & E as a principal decision variable. Agricultural productivity changes were attributed to lagged values of

production oriented public agricultural R & E, changes in farmer's education, and weather. Several coefficients in the model came from a production function similar to the one estimated by Cline and Lu (1976). They used the model to project agricultural productivity growth under three alternative R & E growth rate scenarios as well as to project growth due to a few specific emerging technologies. They also estimated benefit cost ratios and internal rates of return to R & E.

Knutson and Tweeten (1979) used a model similar to the one employed by Lu, Quance, and Liu. Both studies also used the USDA-ESCS National-Interregional Projections (NIRAP) System to project farm output and prices resulting from a projected change in agricultural productivity.

White, Havlicek, and Otto (1978) analyzed investment patterns for agricultural research and extension that would result in optimal agricultural growth. They first estimated the effects on aggregate U.S. agricultural productivity in a manner similar to that of Lu, Quance, and Liu. Then they used control theory to determine an optimal level and time path of research expenditures to attain a certain rate of increase in farm prices under selected conditions. Finally they examined the effects of a reduction in agricultural research funding including its net impact on consumer costs (increased expenditures for food - savings in taxes to fund the research).

Simulation models have received more widespread use for research evaluation in the private industrial sector than for public agricultural research evaluation. This may be partly due to the fact that the industrial research process is better understood and or more tightly planned and controlled. All of the studies reviewed thus far rely on past yield increases or scientists' estimates of future yield increases to estimate the yield effects of new or expanded crop or livestock research programs.

Kislev and Rabiner (1978) have called this a "black box" treatment of the
process of the creation of technical change. They feel that the research
evaluator should try to open up that box and uncover the factors which
affect progress in a given research line. Using the Israeli dairy herd
as an example they built a simulation model of a breeding program for
increased milk production. They defined an ideal breeding model and attempted
to explain the gap between progress made in the real breeding program and
in the ideal system. They explained virtually all the gap in terms of the
"laws of motion" of the breeding operation. They incorporated in the
model principles of quantitative genetics and identified and quantified
the decision variables and natural constraints which limit the effectiveness
of the selection process. This information is useful for ex ante research
evaluation because it provides a guide as to which factors are most
constraining in the research process. And to the extent that one can
identify physical laws of nature governing the rate of technical change,
one's confidence in projections on progress due to research is enhanced.

3.4 Mathematical Programming Approach

The simulation studies discussed in the previous section did not
rely heavily on optimizing techniques with the exception of that of White,
Havlicek, and Otto (1978). This section describes two studies which have
used mathematical programming to examine the question of optimal allocation
of a given research budget.

Russell (1975) developed a model called the Resource Allocation System
For Agricultural Research (RASAR) in the United Kingdom to assist in
selecting a portfolio of government sponsored agricultural research projects.

He first established an overall goal of producing outputs "needed to permit
the attainment of an ideal state for social welfare" (p. 34). Three
dimensions of this goal were identified (consumption, security, and equity)
along with nine aspects of these three dimensions and a rating system.
Unlike the scoring models described previously, Russell used a mathematical
programming model to maximize utility from the research program. His model
provided information on (1) the set of projects to comprise the research
program, (2) the level of financing for each project, (3) the marginal
utility which could be derived from investing in extra units of resources
for the research program and for each project, and (4) the sensitivity
of project selection to varying weights on goals. The system was tested
on a group of research projects at Scottish research establishments.

Cartwright (1971) developed a model which focused on allocation of
research resources within a department of agricultural economics. He
analyzed the decision problems of (1) choosing research areas to work in
and (2) choosing a research job portfolio. To analyze the first problem he
set up a non-linear integer programming problem which made use of a staff
preference function and information on (1) researcher time (2) the amount of
funds that new research areas would bring into the department, and (3) the
number of new staff positions that would be created. The job portfolio
selection model assumed a centralized decision process and required similar
information. The models were not developed far enough to make their use
practical in routine decision making (Schuh and Tollini, 1977, p. 69).

It would appear that the major difficulty in using programming
to guide research resource allocation comes from specifying the necessary
preference function. The other studies described in this review (with the
exception of the scoring models) emphasized the quantification of the level

and or distribution of returns to research but did not require

elicitation of decision makers' preferences.[10/] Thus they were primarily

positive rather than normative techniques.

4. CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

Optimal resource allocation for agricultural research is dependent

on the nature of the market for research results and the technological

characteristics of the research process itself. Private firms tend to

underinvest from a societal viewpoint in many types of agricultural

research because much of the knowledge generated is a free good once it is

produced and thus it is not appropriable by the firm producing it. Also,

research is inherently a risky process which diminishes the private in

incentive to invest in it. Governments have recognized these facts and

have, as a result, invested substantially in the agricultural research

process.

A diversity of approaches have been employed over the past twenty-

five years to evaluate the public investment in research. Some studies

have refined previous attempts at the same methodology. Others have used

different methodology either because they had fewer resources to conduct

the study or because they were trying to answer different questions.

No one approach to evaluation is clearly superior to the others in all

situations. It is theoretically possible to develop a model to incorporate

all of the issues at each level of aggregation addressed by the studies

included in this review. Such a model would, however, consume enormous

resources and personnel time.

10/ Decision makers refers to government officials at the state or national
    level and/or research administrators at the university or academic
    department levels.

Goals must be established before research priorities can be set. These goals exist at various levels, they often conflict, and a single research project often bears on multiple goals. The more normative the study the more important it is to elicit the goals of the relevant decision makers and quantify the tradeoffs among their goals. All research evaluation studies, however, deal implicitly if not explicitly with goals. Many of them have recognized that equity may be an important goal and have examined distributional effects. The aggregate effects on consumers and/or producers and the effects on consumers and producers at various income levels have been studied. Some have looked at the effects of research on the relative productivity of input categories such as land and capital and therefore on their relative shares of income. A few, for example Schmitz and Seckler (1970), have accounted for secondary impacts such as displaced resources, environmental effects, or regional impacts. The fact that these effects have been examined implies that the research evaluator felt them to bear on the goals of the decision maker or society at large.

If the purpose of the research evaluation is to provide a guide to how research resources should be allocated to maximize their payoff an ex ante analysis is needed. An important issue then is whether systematic analysis by means that lead to quantification of benefits and costs can improve the decision making which currently takes place. This leads to the question of how to quantify or evaluate returns to noncommodity research. Here there is a problem of defining output and measuring it. Agricultural economists have not yet been able to estimate quantitatively the value of much of their own research.

Also at issue in research evaluation is the problem of evaluating
basic research. The outcome of basic research is general knowledge, the
relevance of which may not be readily apparent. It is hard to place a
value on such knowledge or to predict its quantity in the research
process. There is a certain amount of serendipity or luck involved in
research discoveries. Furthermore, there is a need to place a value on
the training component of research.

One must recognize that economic policy can greatly affect the rate
of return to agricultural research. Trade policies, for example, affect
prices of outputs relative to inputs and affect the return to research.
A change in trade policy could cause nonadoption of research results
which at first it appeared would be highly profitable.

The value of maintenance research is usually neglected. It could be
argued that over time maintenance of crop and livestock yields has increasingly
become a larger proportion of total research benefits.

These are some of the issues involved and while it is evident that
a rich set of research evaluation procedures have already been developed,
there is need for additional work. It would appear that the three areas
most in need of further methodological work are: (1) the evaluation of
noncommodity research (2) the procedure for uncovering and quantifying
the factors which most affect progress in given research lines in order to
increase our confidence in ex ante projections of yield or cost effects and
(3) the importance of the private sector-public sector interaction in
agricultural research.

Progress is being made in research evaluation, however, as evidenced
by the flow of evaluation studies presented in this paper. At least some
of them have used credible methodology and produced results of useful quality.

CITED REFERENCES

Akino, M. and Y. Hayami, "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development," _American Journal of Agricultural Economics_, Vol. 57, No. 1, February 1975, pp. 1-10.

Araji, A. A., R. J. Sim, and R. L. Gardner, "Returns to Agricultural Research and Extension Programs: An Ex-Ante Approach," _American Journal of Agricultural Economics_, Vol. 60, No. 5, December 1978, pp. 964-968.

Arndt, T. M., D. G. Dalrymple, and V. W. Ruttan, _Resource Allocation and Productivity in National and International Agricultural Research_, University of Minnesota Press, Minneapolis, 1977.

Ayer, H. W. and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," _American Journal of Agricultural Economics_, Vol. 54, No. 4, Part I, November 1972, pp. 557-569.

Barletta, A. N., "Costs and Social Benefits of Agricultural Research in Mexico," Ph.D. dissertation, University of Chicago, 1970.

Bredahl, M. E., "The Productivity and Allocation of Research at U.S. Agricultural Experiment Stations," Unpublished Ph.D. dissertation, University of Minnesota, 1975.

Bredahl, M. and W. Peterson, "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations," _American Journal of Agricultural Economics_, Vol. 58, No. 4, Part I, November 1976, pp. 684-692.

Cartwright, R. W., "Research Management in a Department of Agricultural Economics," Ph.D. dissertation, Department of Agricultural Economics, Purdue University, 1971.

Cline, P. L., "Sources of Productivity Change in United States Agriculture," Unpublished Ph.D. dissertation, Oklahoma State University, 1975.

Cline, P. L. and Y. C. Lu, "Efficiency Aspects of the Spatial Allocation of Public Sector Agricultural Research and Extension in the United States," _Regional Science Perspectives_, Vol. 6, 1976, pp. 1-16.

Currie, J. M., J. A. Murphy, and A. Schmitz, "The Concept of Economic Surplus and Its Use in Economic Analysis," _The Economic Journal_, Vol. 81, December 1971, pp. 741-798.

Davis, J., "A Comparison of Alternative Procedures for Calculating the Rate of Return to Agricultural Research Using the Production Function Approach," Department of Agricultural and Applied Economics, University of Minnesota, March 1979 (mimeo).

Duncan, R. C., "The Gains from Pasture Research in Australia: An Economic Analysis of Research in the C.S.I.R.O. Division of Plant Industries," Unpublished Ph.D. dissertation, Australian National University, 1972(a).

Duncan, R., "Evaluating Returns to Research in Pasture Improvement," _Australian Journal of Agricultural Economics_, Vol. 16, No. 3, December 1972(b), pp. 153-168.

Easter, K. W. and G. Norton, "Potential Returns from Increased Research Budget for the Land Grant Universities," _Agricultural Economics Research_, Vol. 29, No. 4, October 1977, pp. 127-133.

Eddleman, B. R., "Evaluation of Economic Benefits from Agricultural Production Research and Implications for Marketing," in _Proceedings of National Workshop on Coordination of Marketing Research_, 1977, pp. 29-41.

Evenson, R. E., "The Contribution of Agricultural Research and Extension to Agricultural Production," Unpublished Ph.D. dissertation, The University of Chicago, 1968.

Evenson, R. E., "The Contribution of Agricultural Research to Production," _Journal of Farm Economics_, Vol. 49, December 1967, pp. 1415-1425.

Evenson, R. E., "International Transmission of Technology in Sugarcane Production," Yale University, 1969 (mimeographed).

Evenson, R. E., "The Green Revolution in Recent Development Experience," _American Journal of Agricultural Economics_, Vol. 56, No. 2, May 1974, pp. 387-393.

Evenson, R. E., "A Century of Agricultural Research and Productivity Changes, Research, Invention, Extension, and Productivity Change in U.S. Agriculture: An Historical Decomposition Analysis," Paper prepared for the Symposium on Agricultural Research and Extension Evaluation, Moscow, Idaho, May 21-23, 1978.

Evenson, R. and H. P. Binswanger, "Technology Transfer and Research Resource Allocation," in Binswanger, Ruttan, _et al._, ed., _Induced Innovation, Technology, Institutions, and Development_, Johns Hopkins University Press, Baltimore, 1978.

Evenson, R. and D. Jha, "The Contribution of Agricultural Research Systems to Agricultural Production in India," _Indian Journal of Agricultural Economics_, Vol. 28, 1973, pp. 212-230.

Evenson, R. and Y. Kislev, "Research Productivity in Wheat and Maize," _Journal of Political Economy_, Vol. 81, 1973, pp. 1309-1329.

Evenson, R. and Y. Kislev, _Agricultural Research and Productivity_, New Haven and London, Yale University Press, 1975.

Fishel, W. L., "The Minnesota Agricultural Research Resource Allocation Information System and Experiment," in W. L. Fishel, ed., _Resource Allocation in Agricultural Research_, University of Minnesota Press, Minneapolis, 1971.

Fishel, W. L., _Resource Allocation in Agricultural Research_, University of Minnesota Press, Minneapolis, 1971.

Fishelson, G., "Returns to Human and Research Capital, United States Agriculture, 1949-1964," Unpublished Ph.D. dissertation, North Carolina State University, 1968.

Fishelson, G., "Returns to Human and Research Capital and the Non-South Agricultural Sector of the United States, 1949-1964," American Journal of Agricultural Economics, Vol. 53, February 1971, pp. 129-131.

Griliches, Z., "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, Vol. 66, October 1958, pp. 419-431.

Griliches, Z., "Research Expenditures, Education, and the Aggregate Agricultural Production Function," American Economic Review, Vol. 54, December 1964, pp. 961-974.

Grossfield, K. and J. P. Heath, "The Benefit and Cost of Government Support for Research and Development: A Case Study," The Economic Journal, Vol. 76, 1966, p. 537.

Hertford, R. and A. Schmitz, "Measuring Economic Returns to Agricultural Research," in T. A. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Hertford, R., J. Ardila, A. Rocha, and L. Trujillo, "Productivity of Agricultural Research in Colombia," in T. A. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Hines, J., "The Utilization of Research in Development: Two Case Studies in Rural Modernization and Agriculture in Peru," Ph.D. dissertation, Princeton University, 1972.

Industries Assistance Commission Report, Financing Rural Research, Australian Government Publishing Service, Canberra, 1976, pp. 145-277.

Jarrett, F. G. and R. K. Lindner, "Research Benefits Revisited," Review of Marketing and Agricultural Economics, Vol. 45, No. 4, December 1977.

Kahlon, A. S., H. K. Bal, P. N. Saxena, and D. Jha, "Returns to Investment in Research in India," in T. A. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Kaldor, D. R., "A Framework for Establishing Research Priorities," Journal of Farm Economics, Vol. 48, No. 5, December 1966, pp. 1629-1640.

Kislev, Y. and R. Evenson, "Investment in Agricultural Research and Extension: An International Survey," Economic Development and Cultural Change, Vol. 23, No. 3, 1975.

Kislev, Y. and M. Hoffman, "Research and Productivity in Wheat in Israel," Journal of Development Studies, Vol. 14, 1978, pp. 166-181.

Kislev, Y. and U. Rabiner, "On the Economics of Applied Research--The Case of Animal Breeding," Department of Agricultural and Applied Economics, University of Minnesota, 1978 (mimeo).

Knutson, M. and L. Tweeten, "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension," American Journal of Agricultural Economics, Vol. 61, No. 1, February 1979, pp. 70-76.

Lindner, R. K. and F. G. Jarrett, "Supply Shifts and the Size of Research Benefits," American Journal of Agricultural Economics, Vol. 60, No. 1, February 1978, pp. 48-64.

Lu, Y., L. Quance, and C. L. Liu, "Projecting Agricultural Productivity and Its Economic Impact," American Journal of Agricultural Economics, Vol. 60, No. 5, December 1978, pp. 976-980.

Mahlstede, J. P., "Long-Range Planning at the Iowa Agricultural and Home Economics Experiment Station," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Nagy, J. G. and W. H. Furtan, "Economic Costs and Returns from Crop Development Research: The Case of Rapeseed Breeding in Canada," Canadian Journal of Agricultural Economics, Vol. 26, No. 1, 1978, pp. 1-14.

Paulsen, A. and D. R. Kaldor, "Evaluation and Planning of Research in the Experiment Station," American Journal of Agricultural Economics, Vol. 50, No. 5, 1968, pp. 1149-1162.

Peterson, W. L., "Returns to Poultry Research in the United States," Unpublished Ph.D. dissertation, University of Minnesota, 1966.

Peterson, W. L., "The Returns to Investment in Agricultural Research in the United States," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Peterson, W. L., "Return to Poultry Research in the United States," Journal of Farm Economics, Vol. 49, August 1967, pp. 656-669.

Pinstrup-Anderson, P. and D. Franklin, "A Systems Approach to Agricultural Research Resource Allocation in Developing Countries," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Pinstrup-Anderson, P., N. R. de Londoño, and E. Hoover, "The Impact of Increasing Food Supply on Human Nutrition: Implications of Commodity Priorities in Agricultural Research and Policy," American Journal of Agricultural Economics, Vol. 58, No. 2, May 1976, pp. 131-142.

Ramalho de Castro, J. P. and G. E. Schuh, "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Russell, D. G., "Resource Allocation in Agricultural Research Using Socio-Economic Evaluation and Mathematical Models," _Canadian Journal of Agricultural Economics_, Vol. 23, No. 2, 1975.

Sarhangi, R. F., J. Logan, R. C. Duncan, and P. Hagan, "Who Benefits from Agricultural Research: Comment," _Review of Marketing and Agricultural Economics_, Vol. 45, No. 4, December 1977.

Schmitz, A. and G. Seckler, "Mechanical Agriculture and Social Welfare: The Case of the Tomato Harvester," _American Journal of Agricultural Economics_, Vol. 52, No. 4, November 1970, pp. 569-578.

Schuh, G. E. and H. Tollini, _Assessing Monitoring Agricultural Research_, Purdue University, September 1977 (mimeographed).

Schultz, T. W., _The Economic Organization of Agriculture_, McGraw Hill, New York, 1953.

Scobie, G. M., "Who Benefits from Agricultural Research?" _Review of Marketing and Agricultural Economics_, Vol. 44, No. 4, December 1976, pp. 197-202.

Scobie, G. M. and R. T. Posada, "The Impact of Technical Change of Income Distribution: The Case of Rice in Colombia," _American Journal of Agricultural Economics_, Vol. 60, No. 1, February 1978, pp. 85-91.

Shumway, C. R., "Allocation of Scarce Resources to Agricultural Research: Review of Methodology," _American Journal of Agricultural Economics_, Vol. 55, No. 4, November 1973, pp. 557-566.

Shumway, C. R., "Models and Methods Used to Allocate Resources in Agricultural Research: A Critical Review," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., _Resource Allocation and Productivity in National and International Agricultural Research_, University of Minnesota Press, Minneapolis, 1977.

Shumway, C. R. and R. J. McCracken, "Use of Scoring Models in Evaluating Research Programs," _American Journal of Agricultural Economics_, Vol. 57, No. 4, November 1975, pp. 714-718.

Sim, R. J. and R. L. Gardner, "A Review of Research and Extension Evaluation in Agriculture," American Agricultural Economics Research Series No. 214, University of Idaho, May 1978.

Tosterud, R. J., J. C. Gilson, A. E. Hannah, and B. R. Stefansson, "Benefit-Cost Evaluation of Research Relating to the Development of Selkirk Wheat and Target Rapeseed," in C. B. Davidson, ed., _Proceedings of 1971 Symposium on Agricultural Research_, Vol. I, University of Manitoba, Department of Agricultural Economics, Farm Management Occas. Series No. 4, March 1973, pp. 149-199.

Tweeten, L. G. and F. K. Hines, "Contribution of Agricultural Productivity to National Economic Growth," _Agricultural Science Review_, Vol. III, No. 2, pp. 40-45.

U.S.D.A., A National Program of Research for Agriculture, Washington, D.C., U.S. Government Printing Office, 1966.

U.S.D.A., Science and Education Staff, Manual of Classification of Agricultural and Forestry Research, June 1970.

Wennergren, E. B. and M. D. Whitaker, "Social Return to U.S. Technical Assistance in Bolivian Agriculture: The Case of Sheep and Wheat," American Journal of Agricultural Economics, Vol. 59, No. 3, August 1977, pp. 565-569.

White, F., J. Havlicek, and D. Otto, "Agricultural Research and Extension Investment Needs and Growth in Agricultural Production," Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Paper No. 33, November 1978.

Williamson, J. C., "The Joint Department of Agriculture and State Experiment Stations Study of Research Needs," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

UNCITED REFERENCES

CONSUMER AND PRODUCER SURPLUS APPROACH

Ayer, H. W. and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Reply," _American Journal of Agricultural Economics_, Vol. 56, No. 1, February 1974, pp. 175-176.

Ayer, H. W. and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Reply," _American Journal of Agricultural Economics_, Vol. 56, No. 1, February 1974, pp. 178-179.

Ayer, H. W. and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Reply," _American Journal of Agricultural Economics_, Vol. 56, No. 4, November 1974, pp. 842-844.

Bonig, W., "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Comment," _American Journal of Agricultural Economics_, Vol. 56, No. 1, February 1977, p. 177.

Dalrymple, D. G., "Evaluating the Impact of International Research on Wheat and Rice Production in the Developing Nations," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., _Resource Allocation and Productivity in National and International Agricultural Research_, University of Minnesota Press, Minneapolis, 1977.

Duncan, R. and C. Tisdell, "Research and Technical Progress: The Returns to Producers," _Economic Record_, Vol. 47, 1971, pp. 124-129.

Hayami, Y. and M. Akino, "Organization and Productivity of Agricultural Research Systems in Japan," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., _Resource Allocation and Productivity in National and International Agricultural Research_, University of Minnesota Press, Minneapolis, 1977.

Hill, W. G., "Investment Appraisal for National Breeding Programmes," _Animal Production_, Vol. 13, 1971, pp. 37-50.

Logan, S. A., "Evaluating Financial Support of Research Progress," _Journal of Farm Economics_, Vol. 46, 1964, pp. 188-199.

Mohr, G., "Agricultural Research and the Returns to Consumers," _Review of Marketing and Agricultural Economics_, Vol. 45, No. 4, December 1977, pp. 200-204.

Musalem, A. R., "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Comment," _American Journal of Agricultural Economics_, Vol. 56, No. 4, November 1974, pp. 837-839.

Peterson, W. L., "A Note on the Social Returns to Private Agricultural Research and Development," _American Journal of Agricultural Economics_, Vol. 58, No. 2, May 1976, pp. 324-326.

Pinstrup-Anderson, P., "Decision Making in Food and Agricultural Policy: The Distribution of Benefits from New Agricultural Technology Among Consumer Income Strata," _Agricultural Administration_, Vol. 4, No. 1, January 1977, pp. 13-28.

Saylor, R. G., "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Comment," _American Journal of Agricultural Economics_, Vol. 56, No. 1, February 1974, pp. 171-174.

Saylor, R. G., "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Further Comments," _American Journal of Agricultural Economics_, Vol. 56, No. 4, November 1974, pp. 840-841.

Tweeten, L., "Distribution of Benefits and Costs of Agricultural Research and Education," Oklahoma Agricultural Experiment Station, in _Oklahoma Current Farm Economics_, Vol. 46, No. 3, October 1973, pp. 3-7.

Wise, W. S., "The Role of Cost-Benefit Analysis in Planning Agricultural R and D Programmes," _Research Policy_, Vol. 4, July 1975, pp. 246-261.

Wise, W. S., "The Economics of Agricultural Research," _Span_, Vol. 21, No. 3, 1978.

PRODUCTION FUNCTION APPROACH

Allen, P. G., "Evaluation of Research Expenditures in California Agriculture," Unpublished Ph.D. dissertation, University of California, Davis, 1972.

Baur, L. L. and C. R. Hancock, "The Productivity of Agricultural Research and Extension Expenditures in the Southwest," _Southern Journal of Agricultural Economics_, Vol. 7, No. 2, December 1975, pp. 117-122.

Dalrymple, D. G., "Public Investment in Agricultural Research and Education: Some Comments," _Journal of Farm Economics_, Vol. 47, November 1965, pp. 1020-1022.

Dalrymple, D. G., "Evaluating the Impact of International Research on Wheat and Rice Production in the Developing Nations," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., _Resource Allocation and Productivity in National and International Agricultural Research_, University of Minnesota Press, Minneapolis, 1977.

Evenson, R. E., "Economic Aspects of the Organization of Agricultural Research," in W. L. Fishel, ed., _Resource Allocation in Agricultural Research_, University of Minnesota Press, Minneapolis, 1971.

Evenson, R. E., "Comparative Evidence on Returns to Investment in National and International Research Institutions," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., _Resource Allocation and Productivity in National and International Agricultural Research_, University of Minnesota, Minneapolis, 1977.

Kislev, Y., "On Some Aspects of Between Countries Comparisons of Returns to Research," Paper presented at Ford Foundation Workshop on "Seeking Explanations for Different Rates of Return to Agricultural Research," February 2, 1979, New York.

Latimer, R. G. and D. Paarlburg, "Geographic Distribution of Research Costs and Benefits," Journal of Farm Economics, Vol. 47, No. 2, May 1965, pp. 234-241.

Latimer, R. G., "Some Economic Aspects of Agricultural Research and Education in the United States," Unpublished Ph.D. dissertation, Purdue University, 1964.

Lu, Y. C. and P. L. Cline, "Regional Differences in the Rate of Return to Agricultural Research and Extension," Proceedings of the Annual Meeting of the Western Agricultural Economics Association, 48th, 1975, pp. 222-225.

Lu, Y. C. and P. Cline, "The Contributions of Research and Extension to Agricultural Productivity Growth," Paper presented at the American Agricultural Economics Association Annual Meeting, 1975.

Morzuch, B. J., "Technology and Climatic Effects in Aggregate Production Functions," Unpublished Ph.D. dissertation, University of Missouri, 1977.

Puterbaugh, H. L., "Discussion: Evaluation of Agricultural Research Productivity," Journal of Farm Economics, Vol. 49, December 1967, pp. 1439-1442.

Tang, A., "Research and Education in Japanese Agricultural Development," Economic Studies Quarterly, 1963.

te Kloot, J. H. and J. R. Anderson, "Estimation of Technological Change in the Pastoral Zone," Review of Marketing and Agricultural Economics, Vol. 45, No. 4, December 1977, pp. 159-166.

Welch, F., "Formal Education and the Distributional Effects of Agricultural Research," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

SCORING MODELS

Brinegar, G. K., "Discussion -- A Framework for Establishing Research Priorities," Journal of Farm Economics, Vol. 48, 1966, pp. 1638-1640.

Herendeen, J. B., "A Framework for Establishing Research Priorities: Comment," Journal of Farm Economics, Vol. 49, No. 3, August 1967, pp. 741-743.

Kaldor, D., "A Framework for Establishing Research Priorities: Reply," Journal of Farm Economics, Vol. 49, No. 3, August 1967, pp. 743-745.

EXANTE BENEFIT-COST APPROACH

Araji, A. A. and W. C. Sparks, Economic Value of Agricultural Research: A Case
    Study -- Potato Storage Research, University of Idaho, Agricultural Experi-
    ment Station Research Bulletin No. 101, March 1977.

SIMULATION APPROACH

Auer, L., "Measuring the Social and Economic Benefits of Publicly Supported
    Agricultural Research," in C. B. Davidson, ed., Proceedings of 1971
    Symposia on Agricultural Research, University of Manitoba, Department of
    Agricultural Economics, Farm Management Occas. Series No. 4, Vol. I,
    March 1973, pp. 75-123.

de Janvry, A., "Inducement of Technological and Institutional Innovations:
    An Interpretative Framework," in T. M. Arndt, D. G. Dalrymple, and V. W.
    Ruttan, ed., Resource Allocation and Productivity in National and Inter-
    national Agricultural Research, University of Minnesota Press, Minneapolis,
    1977.

MATHEMATICAL PROGRAMMING APPROACH

Hildreth, R. J., "Issues and Implications in Current Procedures for Establishing
    Research Priorities," Journal of Farm Economics, Vol. 48, No. 5, December
    1966, pp. 1647-1648.

Mankower, M. S., "Resource Allocation in Agricultural Research: Some Comments
    on Russell's RASAR," Canadian Journal of Agricultural Economics, Vol. 23,
    No. 3, November 1975, pp. 67-71.

DESCRIPTIVE, PURELY THEORETICAL AND OTHER RELATED STUDIES

Abel, M. E. and D. E. Welsch, "Environmental Constraints, Commodity Mix and
    Research Resource Allocation," in T. M. Arndt, D. G. Dalrymple, and V. W.
    Ruttan, ed., Resource Allocation and Productivity in National and Inter-
    national Agricultural Research, University of Minnesota Press, Minneapolis,
    1977.

Andavawewa, A. B., "Evaluation of Public Research Programs in Agriculture,"
    Canadian Journal of Agricultural Economics, Vol. 39, November 1969,
    pp. 157-169.

Arndt, T. M. and V. W. Ruttan, "Valuing the Productivity of Agricultural
    Research: Problems and Issues," in T. M. Arndt, D. G. Dalrymple, and V. W.
    Ruttan, ed., Resource Allocation and Productivity in National and Inter-
    national Agricultural Research, University of Minnesota Press, Minneapolis,
    1977.

Babb, E. M. and J. E. Pratt, "Changes in Agricultural Productivity and Funding for Research and Extension Education in Indiana, 1964-1977," Agricultural Experiment Station Bulletin No. 205, Department of Agricultural Economics, Purdue University, October 1978.

Bayley, N. D., "Research Resource Allocation in the Department of Agriculture," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Bayley, N. D., "Allocation of Resources to Agricultural Research: A Federal Viewpoint," National Research Council Agricultural Research Institute Proceedings, 20th, 1972, pp. 45-52.

Binswanger, H. P., "Measuring the Impact of Economic Factors on the Direction of Technical Change," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Boyce, J. K. and R. E. Evenson, "Agricultural Research and Extension Programs: National and International," Agricultural Development Council, Inc., 630 Fifth Avenue, New York, New York 10020, 1975.

Brady, N. C., "The International Rice Research Institute (IRRI) Outreach Program," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Browning, G. M., "Discussion: Evaluation of Agricultural Research Productivity," Journal of Farm Economics, Vol. 49, December 1967, pp. 1436-1439.

Chudleigh, P., "The Improvement of Resource Allocation in Agricultural Research in Kenya," Agricultural Administration, Vol. 3, No. 2, April 1976, pp. 93-107.

Crawford, J. G., "Development of the International Agricultural Research System," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Crawford, J. G., "The Future of the International System: A View from the Inside," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan., ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Davidson, C. B., ed., Proceedings of 1971 Symposia on Agricultural Research, University of Manitoba, Department of Agricultural Economics, Farm Management Occas. Series No. 4, Vol. I and II, March 1973.

Dever, D. A., "Cost Benefit in Agricultural Research," Proceedings of the Annual Meeting of the Agricultural Pesticide Society, 22nd, 1975, pp. 67-71.

Downey, C. G. E. and G. E. Labiberti, "Measuring the Benefits of Agricultural Engineering Research," in C. B. Davidson, ed., Proceedings of 1971 Symposia on Agricultural Research, University of Manitoba, Department of Agricultural Economics, Farm Management Occas. Series No. 4, Vol. II, March 1973, pp. 141-166.

Eddleman, B. R., "Benefits from Investment in Food and Agricultural Research Projects," Feedstuffs, Vol. 48, No. 8, February 21, 1977, pp. 24, 32.

Evenson, R. E., "Cycles in Research Productivity in Sugarcane, Wheat and Rice," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota, Minneapolis, 1977.

Fedkew, J. and H. W. Hjort, "The PPB Approach to Research Evaluation," Journal of Farm Economics, Vol. 49, December 1967, pp. 1426-1433.

Gilchrist, V., "Criteria Involved in the Allocation of Agricultural Research Resources," in C. G. Davidson, ed., Proceedings of 1971 Symposia on Agricultural Research, University of Manitoba, Department of Agricultural Economics, Farm Management Occas. Series No. 4, Vol. II, March 1973, pp. 189-220.

Guttman, J., "Agricultural Research: A Study of the Demand for Public Goods," The Rand Paper Series P-5713, September 1976.

Hanson, H., "The International Maize and Wheat Improvement Centre (CIMMYT) Outreach Program," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Heady, E. O., "Public Purpose in Agricultural Research and Evaluation," Journal of Farm Economics, Vol. 43, 1961, pp. 566-581.

Heady, E. O., "Welfare Implications of Agricultural Research," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Hightower, J., Hard Tomatoes, Hard Times, A Report of the Agribusiness Accountability Project on the Failure of America's Land Grant Complex, Schenburm Publishing Co., Cambridge, Massachusetts, 1973.

Hurter, A. P. and A. H. Rubenstein, "Decision Making Mechanisms for Research in the Private Sector," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Jensen, H. R., "Technological Research in Relation to Adjustments," in E. O. Heady, H. Diesslin, H. R. Jensen, and G. L. Johnson, ed., Agricultural Adjustment Problems in a Growing Economy, Iowa State University Press, Ames, 1956.

Kaldor, D. R., "Social Returns to Research and the Objectives of Public Research," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Kislev, Y., "A Model of Agricultural Research," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

MacMillan, J. A., "Feasibility of Cost-Benefit Analysis for the Evaluation of Agricultural Research Projects," in C. B. Davidson, ed., Proceedings of 1971 Symposia on Agricultural Research, University of Manitoba, Department of Agricultural Economics, Farm Management Occas. Series No. 4, Vol. I, March 1973, pp. 125-148.

McGregor, R. C., "Resource Allocation for Agriculture: A View from the Bureau of the Budget," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Mehren, G. L., "An Overview of Resource Allocation in Agricultural Research," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Mellor, J. W., "Relating Research Resource Allocation to Multiple Goals," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Meyer, J. H., "The California Academic-Responsive Budget System," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Miklius, W. and J. O. Gerald, "Research Coordination or Invisible Hand," Journal of Farm Economics, Vol. 49, 1967, pp. 756-758.

Moseman, A. H., "Coordinated National Research Projects for Improving Food Crop Production," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Mosher, A. T., "Unresolved Issues in the Evolution of the International System," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Nelson, R. R., "The Simple Economics of Basic Scientific Research," Journal of Political Economy, Vol. 67, June 1959, pp. 297-306.

Pastore, J. and E. R. A. Alves, "Reforming the Brazilian Agricultural Research System," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Parvin, D. W. and F. H. Tyner, "The Systems Approach -- Research on Research Management," Southern Journal of Agricultural Economics, Vol. 6, July 1974, pp. 57-65.

Paulson, A. A., "The Pricing of Research Output," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Peterson, W. L., "Discussion: The PPB Approach to Research Evaluations," Journal of Farm Economics, Vol. 49, No. 5, December 1967, pp. 1434-1436.

Peterson, W. L., "The Allocation of Research, Teaching, and Extension Personnel in U.S. Colleges of Agriculture," American Journal of Agricultural Economics, Vol. 51, No. 1, February 1969, pp. 41-56.

Peterson, W. L., "Returns to Investment in Agricultural Research," University of Minnesota Department of Agricultural and Applied Economics Staff Paper P78-2, February 1978.

Peterson, W. L., "Sources of Differences in Rates of Return to Agricultural Research: Some Observations," Paper presented at Ford Foundation Workshop on "Seeking Explanations for Different Rates of Return to Agricultural Research," February 2, 1979, New York.

Peterson, W. L. and Y. Hayami, "Technical Change in Agriculture," Part VII in L. Martin, ed., A Survey of Agricultural Economics Literature, Vol. 1, University of Minnesota Press, Minneapolis, 1977.

Phillips, J., "A Subjective Evaluation of Resource Allocation Within Agricultural Economics Research: 1958-73," Review of Marketing and Agricultural Economics, Vol. 43, No. 1, March 1975, pp. 52-56.

Pinstrup-Anderson, P. and F. C. Byrnes, ed., Methods for Allocating Resources in Applied Agricultural Research in Latin America, Series CE-11, CIAT, November 1975. (Summary of papers presented at CIAT/ADC Workshop, Cali, Colombia, November 26-29, 1974.)

Plaxico, J. S., "Optimum Allocation of Research Resources in a Dynamic Agriculture," Journal of Farm Economics, Vol. 39, December 1957, pp. 1373-1382.

Puterbaugh, H. J., "An Application of PPB in the Agricultural Research Service," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Robinson, R. R., "Resource Allocation in the Land Grant Universities and Agricultural Experiment Stations," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Ruttan, V., "Bureaucratic Productivity: The Case of Agricultural Research," University of Minnesota Department of Agricultural and Applied Economics Staff Paper P78-16, November 1978.

Ruttan, V. W., "Resource Allocation in Agricultural Research," National Research Council Agricultural Research Institute Proceedings, 20th, 1972, pp. 37-44.

Salisbury, G. W., "Productivity in Agricultural Research," Agricultural Engineering, Vol. 57, No. 4, April 1976, pp. 81-82.

Schnick, A., "The Road to PPB: The Stage of Budget Reform," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Schultz, T. W., "The Allocation of Resources to Research," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Schultz, T. W., "What Are We Doing to Research Entrepreneurship," University of Chicago, Department of Agricultural Economics Paper No. 77:11, March 1977.

Schultz, T. W., "Uneven Prospects for Gains from Agricultural Research Related to Economic Policy," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Sehgal, S. M., "Private Sector International Agricultural Research: The Genetic Supply Industry," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Swanson, B. E., "Impact of the International System on National Research Capacity: The CIMMYT and IRRI Training Programs," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed., Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Tichenor, P. J. and V. W. Ruttan, "Problems and Issues in Resource Allocation for Agricultural Research," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Trelogan, A. C. and N. Townshend-Zellner, "On Benefits of Agricultural Marketing Research," Journal of Farm Economics, Vol. 47, No. 1, February 1965, pp. 36-50.

Tweeten, L., "Benefit-Cost Ratios from Investment in Knowledge," Journal of Farm Economics, Vol. 49, 1967, pp. 744-750.

Tweeten, L., "The Search for a Theory and Methodology of Research Resource Allocations," in W. L. Fishel, ed., Resource Allocation in Agricultural Research, University of Minnesota Press, Minneapolis, 1971.

Tweeten, L. and F. Tyner, "Toward an Optimum Rate of Technological Change," Journal of Farm Economics, Vol. 46, December 1964, pp. 1075-1084.

Ulbricht, T. L. V., "Contract Agricultural Research and Its Effect on Management," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, Minneapolis, 1977.

Wallace, T. D. and D. M. Hoover, "Income Effects of Innovation: The Case of Labor in Agriculture," Journal of Farm Economics, Vol. 48, May 1966, pp. 325-336.

Williams, S. W., S. Strong, and C. B. Baker, "Benefits Stem from Research in Corn Production," Illinois Research, Vol. 15, No. 3, Summer 1973, pp. 3-4.

Williamson, J. C., "Discussion: Issues and Implications in Current Procedures for Establishing Research Activities," Journal of Farm Economics, Vol. 48, December 1966, pp. 1651-1653.

Wood, A. W., "Measuring the Benefits of Agricultural Marketing Research," in
     C. B. Davidson, ed., <u>Proceedings of 1971 Symposia on Agricultural Research</u>,
     University of Manitoba, Department of Agricultural Economics, Farm Manage-
     ment Occas. Series No. 4, Vol. II, March 1973, pp. 121-139.

Wortman, S., "Impact of International Research on the Performance and Objectives
     of National Systems," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed.,
     <u>Resource Allocation and Productivity in National and International Agri-
     cultural Research</u>, University of Minnesota Press, Minneapolis, 1977.