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REVIEW OF METHODS USED TO EVALUATE RETURNS TO AGRICULTURAL RESEARCH

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World expenditures on agricultural research have increased substantially over the past 25 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.1/ Government decisionmakers 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, from much of the knowledge generated by research being 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 from that research. The lack of a market pricing system for research output means that public decisionmakers may also allocate too few or too many resources to research either in the aggregate or to individual research areas.

Several approaches have been employed over the past three decades 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 decisionmaker's 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."

This paper reviews the major research evaluation techniques that have been used. It benefits greatly from previous reviews of evaluation techniques. Peterson (1971) examined techniques and results of studies that measured returns to agricultural research in the United States. Shumway (1973, 1977) concentrated on project-ranking methods and included several techniques that have been applied in evaluating nonagricultural research. Schuh and Tollini, at the request of the Consultative Group For International Agricultural Research (CIGIAR), reviewed methods and procedures that might be applied to CIGIAR programs and activities. More recently, Sim and Gardner examined several frequently used techniques and results. Other partial revisions can be found in papers by Easter and Norton, Peterson and Hayami, and Scobie (1979).

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* evaluations. It attempts to be still more complete in terms of the types of studies reviewed. It does not include methods used exclusively for evaluating nonagricultural research. Major studies which illustrate each technique are discussed and compared.2/ It is hoped that this review will provide some insights into differences in assumptions made in studies using similar methods, techniques that might be appropriate to answer different questions, and incomplete areas where the methodology needs development or improvement.

Ex Post Evaluations

Studies that have made *ex post* evaluations of

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agricultural research can be classified into two major groups: (1) those that 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 that include research as a variable in a production function and estimate a marginal rate of return to research.3/ In addition, two major studies exist that do not fit well into the two classes mentioned above. One estimates the impact of technology on national income and the other measures the nutritional impact of agricultural research.

Consumer and Producer Surplus Approach 4/5/

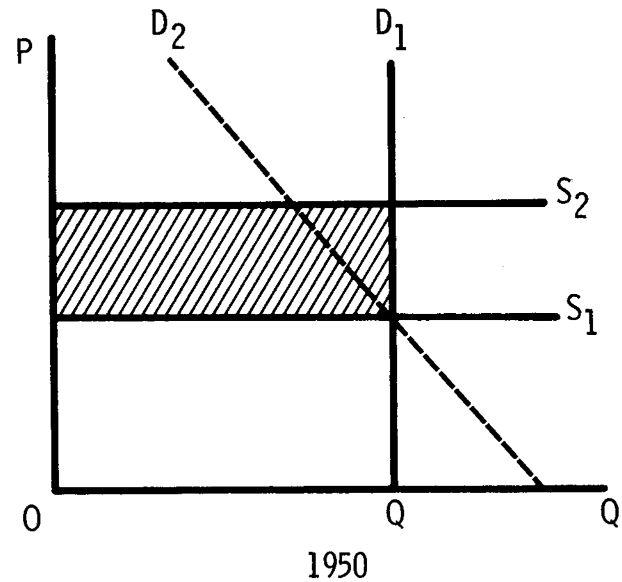
The first major attempt to quantitative evaluation of agricultural research investments was by Schultz (pp. 117-122). He calculated the value of inputs saved in agriculture because of im-roved proved, more efficient production techniques and compared this with the cost of research and development.

As a lower limit, Schultz estimated that output per unit of input was 32% higher in 1950 than in 1910. Thus to have produced 1950 output with 1910 techniques would have required \$9.6 billion more of inputs than the \$30 billion actually used (using 1910-1914 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.

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 sector 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.6/

Schultz estimated the return to agricultural research at the aggregate level. Working at the commodity level, Griliches (1958) calculated the loss in net social 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 (Fig. 2) and perfectly inelastic (Fig. 3) supplies. He implicitly assumed the

Figure 1.



demand elasticity was minus one. In Figure 2, the increase in consumer surplus equals E + F which equals $K P_1 Q_1 (1 - 1/2Kn)$ where $K = \frac{\Delta P}{P_1}$ and n is the demand elasticity. In Figure 3, the increase in consumer surplus equals A + B, the change in producer surplus equals -A + C, and the change in net economic surplus equals $A + B - A + C = K P_1 Q_1 (1 + 1/2 \frac{K}{n})$ where $K = \frac{\Delta Q}{Q_1}$ and n is the absolute value of 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 changes in net social 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.

Peterson's gain in net economic surplus = A + B + C + E + G + (-A - B + H + I + J) = C + E + G + H + I + J. He reasoned that this latter area is approximately equal to I + J + K + L + E + G - D and provided the following formula for approximating this area:

Figure 2.

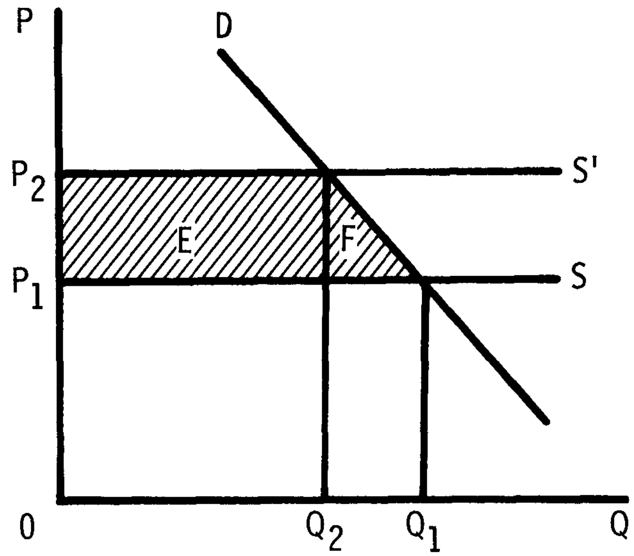
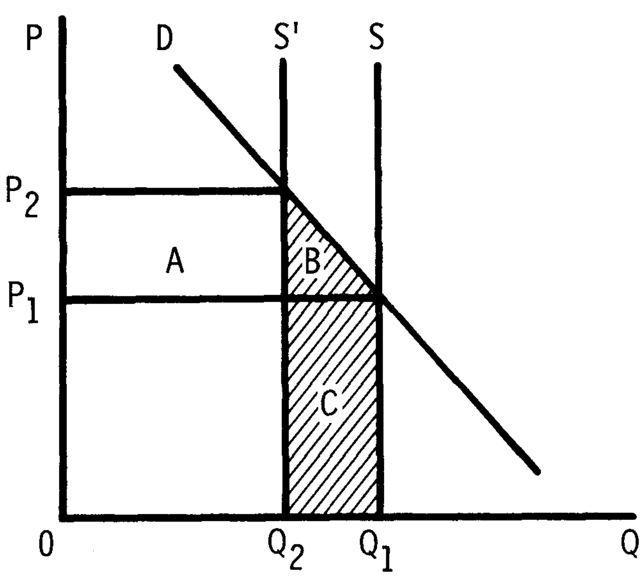


Figure 3.

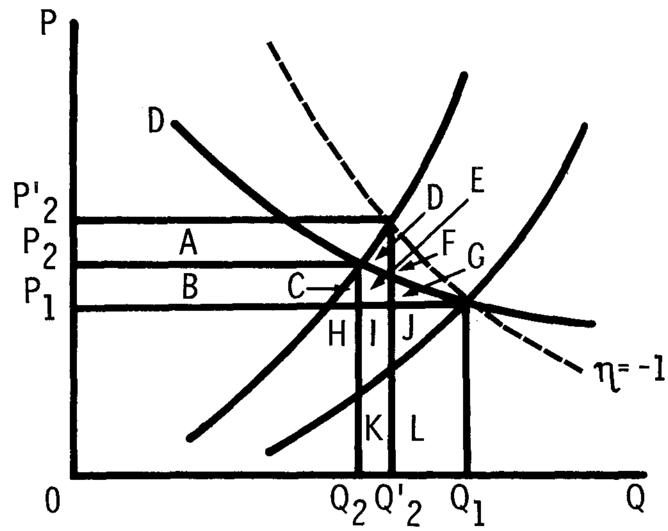


$$(1)\quad KQ_1P_1 + \frac{1/2K^2P_1Q_1}{n} - 1/2Q_2K^2P_1\left(\frac{P_1}{P_2}\right)\left(\frac{en}{n+e}\right)\left(\frac{n-1}{n}\right)^2$$

where n is the absolute value of the demand elasticity, e the supply elasticity, and K the percentage shift in the supply curve $\frac{Q_1-Q'_2}{Q_1}$.

He then compared these benefits with the costs of

Figure 4.



research and extension and calculated an internal rate of return. Note that the above formula reduces to

$$(2)\quad KQ_1P_1(1 + K/2n) \text{ if } n = 1 \text{ or } e = 0.$$

Hertford and Schmitz provided the following formulae for estimating net social surplus when the demand curve and supply curve as represented in Figure 4 are are linear and the supply shift is parallel:

$$(3)\quad \text{Total net social surplus} = KP_1Q_1\left(1 + 1/2\frac{K}{n+e}\right)$$

$$(4)\quad \text{consumers surplus} = \frac{KP_1Q_1}{n+e}\left(1 - 1/2\frac{Kn}{n+e}\right)$$

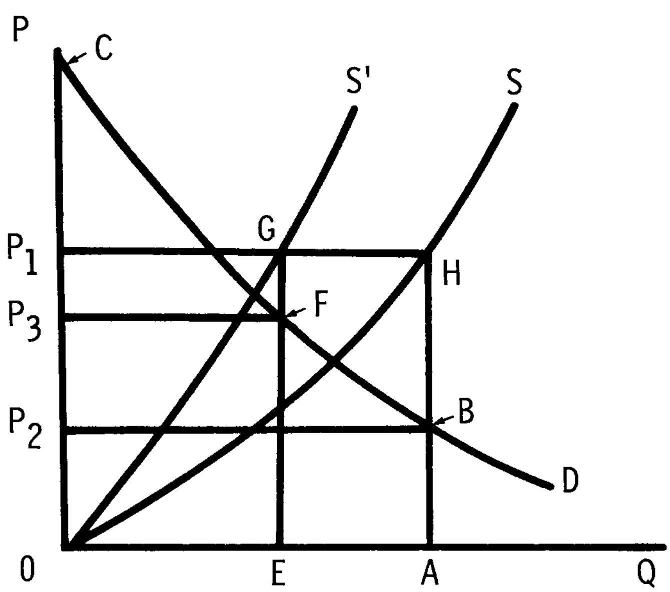
$$(5)\quad \text{Producers surplus} = KP_1Q_1\left\{1 - \frac{1}{n+e}\left(1 - 1/2K\left(\frac{2n+e}{n+e}\right)\right)\right\}$$

where K is defined as the horizontal distance between S_0 and S_1.

Schmitz and Seckler extended the model to take account of resources released with the introduction of the technology (in their example, labor from use of the mechanical tomato harvester). They estimated benefits by Schultz's method of the "value of inputs saved," then estimated the hours of labor lost, multiplied this by the wage rate and subtracted this value from benefits to get a measure of net benefits.7/ The approach assumed that freed-up labor would be unemployed and receive no compensation. In addition, they calculated the net social rate of return assuming alternative levels of compensation for the displaced farmworkers.

Ayer and Schuh (1972) altered the model to incorporate a cobweb behavioral assumption for cotton production in Brazil. The change in social returns equals (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

Figure 5.



collapsed them into two dimensions so that D could be represented by $P - nQ^{\alpha}$, S could be represented by $Q - mP^{\beta}_{t-1}$, and S' could be represented by $Q = (1 - K)\, mP^{\beta}_{t-1}$ where:

n = all parameters and variables influencing demand but excluded from the equation, and

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

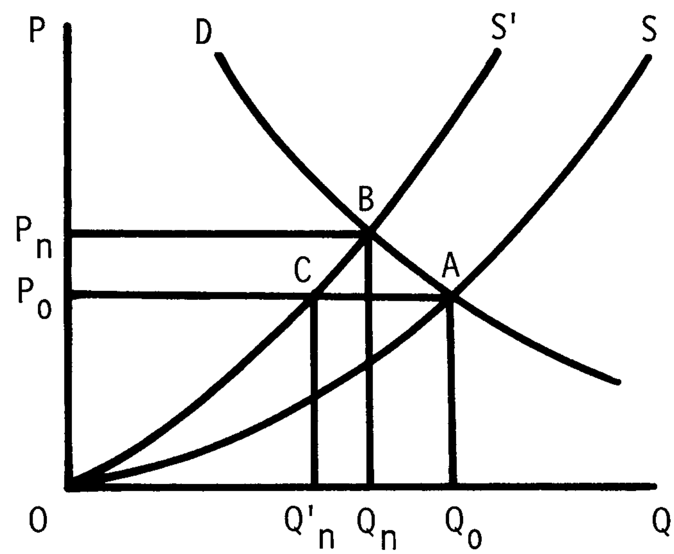
Net social returns were then estimated for each year as follows:

$$(6) \quad \int_0^A (D)\, d(Q) - \int_0^A (S)\, d(Q) - \int_0^E (D)\, d(Q) + \int_0^E (S')\, d(Q).$$

They then compared these returns with the estimated costs of research and development and calculated 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.8/ This article generated a series of comments and replies and in two of them (Musalem; Ayer and Schuh, 1974) there is a discussion of a means for taking account of general equilibrium effects using the consumer-producer surplus approach.

Akino and Hayami used an approach similar to that used by Ayer and Schuh (1972) (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_nBCP_o plus the area ABC. The change in producer surplus equals the area AOC minus the area P_nBCP_o and the change in 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 rice at a total value equivalent to area ACQ'_nQ_o to keep the price at P_o. Therefore, the area $ACQ_nQ'_o$ represents a gain in foreign exchange due to the research. Akino and Hayami provided formulae for estimating P_nBCP_o, ABC, AOC, and ACQ'_nQ_o:

(7) $P_nBCP_o = P_oQ_o \frac{K(1+e)}{e+n} [1 - \frac{1/2K(1+e)n}{e+n} - 1/2K(1+e)]$

(8) $ABC = 1/2P_oQ_o\frac{[K(1+e)]^2}{e+n}$

(9) $AOC = KP_oQ_o$

(10) $ACQ'_nQ_o = (1+e)KP_oQ_o$

where K is the shift in the production function. They mention that the shift in the supply curve can be approximated by $h \approx (1+e)K$. Flores, Moya, Evenson, and Hayami use a model similar to that used by Akino and Hayami to evaluate social returns to rice research in the Philippines.

Scobie and Posada employed the consumer-producer surplus approach in their study 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 benefitted the most, producers suffered losses, but small producers lost the most.

Duncan (1972a, b) used the consumer-producer surplus approach in a somewhat different manner. He estimated the benefits of research that 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 7.

Under certain assumptions the hatched area represents the gross welfare gain from the increase in productivity. He presented the following formula for calculating this area for certain new technologies:

(11) $b(Pe^{-Q_1/b} - Pe^{-Q_2/b}) - P(Q_2 - Q_1)$

where b is the long run price elasticity and

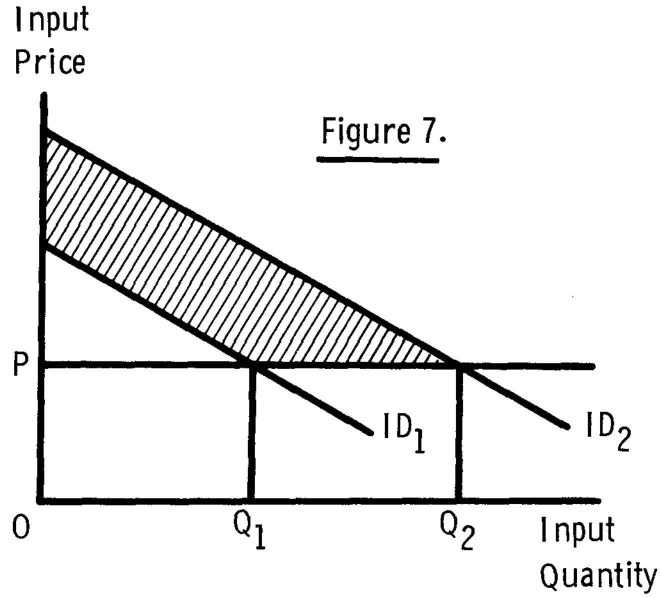


Figure 7.

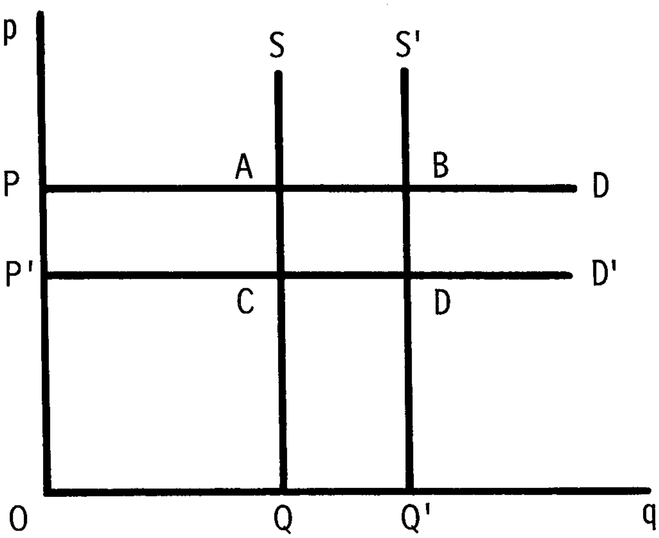
calculated the internal rates of return on the costs associated with the projects generating the new technologies. Finally, he assumed a perfectly elastic demand curve for the final product which implies that the indicated welfare gain accrues to producers.

Ex post benefit cost analyses that have measured net benefits by estimating the increase in production and valuing this at a given constant price also fall into the consumer-producer surplus classification (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 a vertical supply curve (Figure 8).

For example, 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 United States, and the two countries together. Their measure of the change in social benefits can be represented by ABQ' in Figure 8. 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 change in social benefits as the area CDQ'Q.

Kislev and Hoffman estimated returns to research on wheat in Isreal. Since Isreal imports most of its grain, they assumed 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 used yield regressions to determine the yield increases due to new varieties, multiplied those increases by the area

Figure 8.



sown, and then multiplied this value by the world price. They, in effect, estimated the area ABQ´Q in Figure 8.

Several other studies have used this consumer-producer surplus approach including Evenson (1969) for sugar cane in Southern Africa; Barletta for corn and wheat in Mexico; Hines for corn in Peru; Hertford, Ardila, Rocha, and Trujillo for rice, soybeans, wheat, and cotton in Colombia; Nagy and Furtan for rapeseed in Canada and others. Pinstrup-Andersen used the consumer-producer surplus approach but concentrated on the effects of new agricultural technology on consumers at various income levels.

Lindner and Jarrett (1978) have pointed out the importance of recognizing that the total level of annual social benefits from the adaption 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 while mechanical or organizational innovations will be more likely to generate a convergent shift. A parallel shift is also possible. 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.9/

Lindner and Jarrett (1978) also provided a generalized formula for measuring research benefits that avoids some of the biases that arise from varying assumptions about supply shifts and elasticities. Utilizing Figure 9,

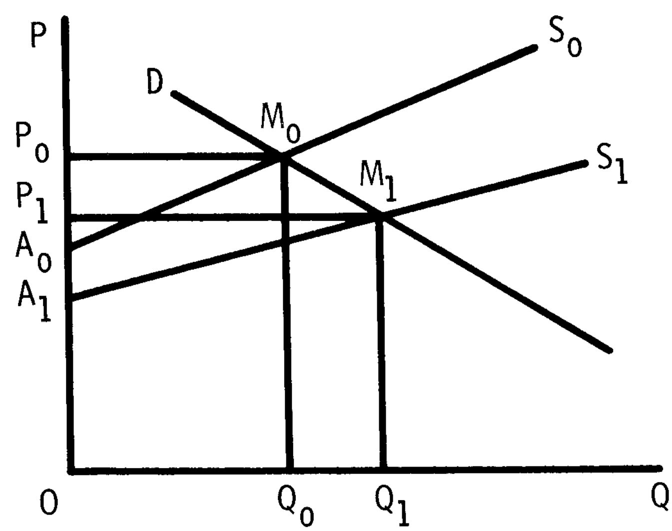
(12) change in total benefits $(A_1M_1M_oA_o)$ = $1/2\ (P_oQ_1 - P_1Q_o + Q_oA_o - Q_1A_1)$,

(13) change in producer benefits = $1/2\ (Q_oA_o - Q_1A_1 - P_oQ_o + P_1Q_1)$, and

(14) change in consumer benefits = $1/2\ (P_oQ_1 - P_1Q_o + P_oQ_o - P_1Q_1)$.

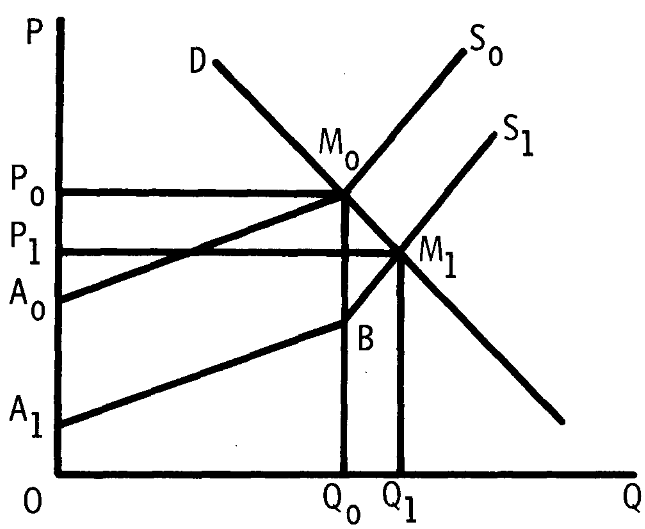
P_o and Q_o are current price and quantity, $P_1 = P_o\ (1-\frac{ke}{e+n})$, $Q_1 = Q_o\ (1 + \frac{ken}{e+n})$ where k is the absolute cost reduction at Q_o divided by P_o, $A_1 = A_o/(1-k)$ for a proportional shift, $A_1 = A_o - R$ where R is the absolute reduction in average costs for all firms for a parallel shift, and $A_1 = A_o$ for a pivotal shift.10/

Figure 9.



Lindner and Jarrett (1978) made a computational error which was subsequently pointed out by Rose and by Wise and Fell. Lindner and Jarrett (1980) point out that it arose because their equations apply only when the supply and demand curves are linear. The procedure used for estimating P_1 and Q_1 from P_o and Q_o using a value of the local elasticity of supply which was not necessarily consistent with the arc elasticity of supply implied by the chosen values of A_1 relative to P_1 and Q_1 violated the linearity assumption. Rose and Wise and Fell suggest the inclusion of a kink in the S_1 curve directly below M_o (see Figure 10).

Figure 10.



Rose suggests the following formula to estimate net social surplus:

(15) $1/2\ Q_0\ (KP_0 + A_0 + A_1) + 1/2\ KP_0(Q_0 - Q_1)$

where the first term represents the area $A_0M_0BA_1$ and the research term corresponds to M_0M_1B. If a parallel shift was assumed, this would reduce to

(16) $KP_0Q_0 + 1/2\ KP_0\ (Q_0 - Q_1)$

and, in the case of a pivoted shift, it reduces to

(17) $1/2\ KP_0Q_0 + 1/2\ KP_0\ (Q_0 - Q_1)$

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 demand functions and in the nature of supply function shifts. The various formulae which have been presented here as well as others in the literature (see, for example, Barletta, Dalyrmple, Ramalho de Castro, and Ardila) reflect these differences as well as differences in the "K" value derivation. Scobie (1976) drew attention to the dissimilar results that could be obtained by applying different formulae found in the literature to the same problem. An exhaustive comparison of types of shifts, elasticities, and K values in the formulae which caused these differences will not be presented here. However, a summary of the main differences and relative importance of the assumptions underlying the Griliches, Peterson, Hertford and Schmitz, Akino and Hayami, Lindner and Jarrett (1978), and Rose formulae is made below.

Griliches assumes a parallel shift (horizontal or vertical); Peterson a proportional shift; Hertford and Schmitz a parallel shift; Akino and Hayami a pivoted shift; Lindner and Jarrett and Rose four types of shifts. The type of shift assumed is very important because divergent shifts result in fewer benefits in total to producers than parallel or convergent shifts. Duncan and Tisdell have shown, for example, that producer returns for research will be negative when research leads to a divergent supply shift and when demand is inelastic. Lindner and Jarrett (1978) point out that this set of assumptions was made by Akino and Hayami and, therefore predetermined their conclusions about the distributional effect of the rice breeding research on Japanese agriculture.

Griliches, Hertford, and Schmitz, and Lindner and Jarrett assume linear supply and demand curves. Peterson assumes a general specification, Akino and Hayami constant elasticity supply and demand curves, and Rose a linear kinked supply curve and a linear demand curve. These differences are likely to be of minor importance in determining net benefits.

Much attention should be devoted to evaluating K since its size is a major determinant of net benefits. In some cases, it is easier to measure K as an output effect (horizonal shift in the supply curve) and in others as the reduction in the supply curve. This distinction between a horizontal and a vertical supply shift is really an artificial one. When yield increases due to technical change this also means that the same output can be produced at a lower cost.

When using a particular formula, one must be careful to use the type of K which corresponds to it. The formula developed by Hertford and Schmitz includes K as a horizontal shifter of the supply curve while Lindner and Jarrett (1978) and Rose use it as a vertical shifter. Akino and Hayami use K as a production function shifter and provide a formula for converting it to a horizontal supply function shifter. Peterson measures K as the proportional change in equilibrium quantity following the supply shift, which is less than Hertford and Schmitz's horizontal distance between the supply curves.

The differences in the various formulae due to the type of shifts, functional forms, and K values are illustrated in equation (3) and in equations (18) - (20) below.

$$(18) \quad KP_1Q_1\left(\frac{1}{1+e} + 1/2\ \frac{K}{e+n}\right)$$

Equation (18) was derived from the formulae found in Akino and Hayami after converting their production function shifter to a supply function shifter. P_1 and Q_1 are the new equilibrium quantity and price after the rightward shift in supply. Note the similarity to equation (3) developed by Hertford and Schmitz. The extra e in the initial term inside the brackets occurs because Akino and Hayami assume a pivotal rather than a parallel shift and a constant elasticity rather than a linear supply curve. If they had assumed a linear supply curve, the first term within the brackets would have equaled 1/2, and, if they had assumed linearity and a parallel shift, the two equations would not differ.

Equations (19) and (20) were derived from equations (16) and (17) substituting Lindner and Jarrett's and Rose's definition of Q_1. These equations,

$$(19) \quad KP_0Q_0\ \left(1 + 1/2\ \frac{ke}{e+n}\right), \text{ and}$$

$$(20) \quad KP_0Q_0\left(1/2 + 1/2\ \frac{ken}{e+n}\right)$$

differ from (3) and (18) because P_0 and Q_0 are equilibrium price and quantity before the supply shift. Also, K is a proportional vertical shift in the supply curve and could be converted to a horizontal shift by the relation K = ke according to Lindner and Jarrett (1978). Equation (19) represents a parallel, and equation (20) a pivoted, shift.

Peterson's formula differs from the others because he measures the area below the demand curve between the old and new equilibrium price as an approximation to the area between the supply curves. In the special case of a perfectly inelastic supply curve, his formula is identical to Hertford and Schmitz's equation (3). Griliches formulae are merely special cases of equation (3) in the perfectly inelastic supply curve case and of Lindner and Jarrett and Rose in the perfectly elastic supply case where new equilibrium price and quantity are used in the derivation of K and where n = 1.

All the equations presented are only approximations, but those formulae which imply supply intercepts on the vertical axis make the most intuitive sense. The others imply that production would occur at a zero price in the long run. The effect of this assumption on the aggregate level of benefits will usually be minor, however, compared to differences in the type of shift assumed.

Thus far little has been said about the importance of the demand elasticity. In general, the more inelastic the demand curve, the more likely producers will lose following technical change. Also, if the supply elasticity is larger than the demand elasticity regardless of the size of the demand elasticity, the consumer will tend to receive a larger share of the benefits relative to producers. In addition, when accounting for secondary effects such as labor displacement resulting from technical change, the size of the price elasticity of demand is important. If it is low, even those technologies which do not directly displace labor can do so as a result of the output effect on product price.

In summary, the consumer producer surplus approach is flexible. It enables estimation of trade and price policy effects as well as distributional effects. This flexibility can also be a liability, however, if the underlying relationships and policies are not accurately mirrored in the analysis. If, for example, a parallel shift in the supply curve is assumed when a divergent shift would have been more appropriate, the estimated benefits would be too large. Or, if a closed economy for a particular crop is assumed when in fact the country involved is a small producer of that commodity and exports it openly on the world market, the producers might gain a good deal more relative to consumers than that implied by the analysis. Differences in consumer-producer surplus formulae are due for the most part to assumptions about the type of supply shift, functional form, and how the shift (K) in the supply curve is measured.

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:

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

where Q = value of agricultural output; A = shift factor; X_i = i^{th} conventional production input; R_{t-j} = expenditures on research (and extension) in the t-jth year; β_i = the production coefficient of the i^{th} conventional input; α_{t-j} = the partial production coefficient of research (and extension) in the $t-j^{th}$ year; and u = random error term.

The major source of variation among studies using a model similar to equation (1) has been in the specification of the length and shape of the time lag for the impact of research expenditure 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, 1971), 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 also have attempted to empirically determine the appropriate length of this lag. For example, for the United States, the concensus suggests a mean lag of six to seven 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) and Davis (1979b) for the United States and Kahlon et al. for India), while others have applied the model to different commodity groups (see, for example, Peterson (1966, 1967) and Bredahl). The latter study, in addition to estimating the marginal internal rate of return (MIRR) to each of the four commodity groups (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).

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

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

where

P = a productivity index of agricultural output; W = weather index;
E = measure of the education level of farmworkers; 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 intercorrelation 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 United States. Cline (see also Lu and Cline) updated and refined Evenson's work for U.S. aggregate agricultural output and the 10 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 United States. 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 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 (see also Evenson, Waggoner, and Ruttan). Due to the unavailability of data for all variables, different specifications of equation (2) were used to analyze the three time periods 1925-1969, 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 United States 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. Evenson, Waggoner, and Ruttan also tested the effect of decentralization of scientists to substations. They found that decentralization of research within a state had a positive effect on the productivity of state research systems.

Other production function studies which analyzed the spillover of research from one state, region, or country to another were conducted by Flores-Moya, Evenson, and Hayami; White and Havlicek; and Garron and White. The latter study separates out effects of "spillouts" and "spillins" of research.

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, who used only commodity-specific research expenditure by the state experiment stations, to Cline, who used total research for commodity and noncommodity research inquiry areas by experiment stations, USDA expenditures, extension expenditure, and soil conservation service expenditure. Alternatively, studies by 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 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, ex post 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) have attempted to estimate the individual partial production coefficients, α_{t-j}. The majority of studies, however, have, in fact, only estimated the total production coefficient $\alpha = \sum_{j=o}^{m} \alpha_{t-j}$. For these studies, the resultant issue has then become how is the total marginal product research, that is, $MPR = \frac{\alpha Q}{R}$, 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 MIRRs from different studies.

The production function approach has proved 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. It also allows one to estimate a marginal as opposed to an average rate of return. One of its major limitations is the data required. It is very difficult, for example, to obtain data on production inputs such as labor, machinery, and chemicals applied on individual commodities. Another limitation is the uncertainty involved with projecting past rates of return into the future. Davis and Peterson (1980) have provided evidence that the production coefficient on the research variable in aggregate agricultural production functions has declined since the 1950s, but remained stable for the past 10-15 years. Also, there is a great deal of intercorrelation among inputs such as land, labor, and machinery.

Change in National Income Approach

"Tweeten and Hines 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." (Easter and Norton, p. 128).

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 marginal returns to research approach zero as the farm population approaches an equilibrium size. This would not appear to be an approach with widespread applicability.

Nutritional Impact Approach

Pinstrup-Andersen, Londoño, and Hoover have developed "a procedure to estimate the nutritional implications 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." (Pinstrup-Andersen, Londoño, and Hoover, p. 131)

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. It does raise the issue, however, that goals other than income can be very important in evaluating research.

Ex Ante Evaluation

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: (a) those that used scoring models to rank research activities, (b) those that employed benefit-cost analysis to establish rates of return to research, (c) those that used simulation models, and (d) those that used mathematical programming to help select an optimal mix of research activities.

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 United States.11/ A task force evaluated the strengths and weaknesses in the research program, identified future research problems and recommended a level of public research investment for the next few years. A major result of this study was the systematic classification of research areas that 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, and Paulson and Kaldor have reported on a scoring model that 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 subareas 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 10 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 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 (RPSs 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, 20 interdisciplinary faculty task forces, 18 extramural scientist panels, and 23 academic departments" (Shumway and McCracken, 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 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 that are difficult to quantify by most other procedures. Scoring models have the potential to facilitate the incorporation of multiple goals. Although this has not been done in the past, theoretically shadow prices could be developed from the results which measure the opportunity cost of selecting one research area over another.

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. *Ex ante* studies have tended to focus on project level evaluations while *ex post* studies have been more macro oriented. Due to the stochastic nature of research results, it is difficult to predict the payoff of individual projects. Because yield increases or cost reductions were projected rather than observed, one of the major differences among *ex ante* benefit-cost studies 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 MARRAIS, 12/ 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. MARRAIS 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.

Ramalho de Castro and Schuh 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 of the direction that research should take. They discussed the effects of technological change in the agricultural sector on the nonagricultural sector and the effects 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 rather than utilizing 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 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% 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 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 United States. 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 (p. 34-35) made use of the multipliers from a national input-output analysis. Gross benefits were measured as changes in other sectors' output resulting from increased output in the agricultural sector. Net benefits were estimated as net wage increases resulting from expanded employment in each of the sectors plus net profit gains in each of the sectors.

Other <u>ex ante</u> benefit-cost studies were conducted by Araji and Sparks for potato research in Idaho and by Barker for rice research in South and Southeast Asia. The latter study compared benefits for different types of environments under which rice is grown.

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

Simulation Approach

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. The MARRAIS model described in the last section could appropriately have been included in this section as well.

Pinstrup-Andersen and Franklin described 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 an identification of changes in product supply, input demand, and farm consumption necessary to achieve those achieve those goals; identification of research problems; and 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. 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) expenditures and agricultural productivity growth by formulating a simulation model including R&E expenditures as a principal decision variable. Agricultural productivity changes were attributed to lagged values of production-oriented public agricultural R&E investments, changes in farmer's education, and weather. Several coefficients in the model came from a production function similar to the one estimates by Cline and Lu (1976). They used the model to project agricultural productivity growth under three alternative R&E investment 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 investments.

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 productivity 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 minus savings in taxes to fund the research).

Scobie developed an alternative simulation needed to determine the optimal level of investment in agricultural research. His model included a production function, supply and demand function, and a discounted cash flow analysis. In the absence of research, output was assumed to grow at a set minimum rate. As investment in research increased, the growth rate of output would increase but at a diminishing rate and become asymptotic to some maximum growth rate. Other assumptions were made about the length of the lag period following research before output would be realized, forms of the supply and demand equations, etc. He varied several of the assumptions or parameters and estimated annual levels of research investments that would generate various internal rates of return.

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. Also, private research and development is likely to be subject to less uncertainty with regard to payoff because it is very "applied" in nature compared to public research which is more "basic." 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 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.

Simulation models have the advantage of being very flexible. They can be used to estimate optimal levels of research at a national level, commodity level, or program level. They can be used to determine the effects of research on prices, income employment, or the parameters. Unless the models are extremely naive, however, a good deal of information and time is required to build them.

Mathematical Programming Approach

The simulation studies discussed in the previous section did not rely heavily on optimizing techniques with the exception of White, Havlicek, and Otto (1978). This section describes two studies that 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 (a) the set of projects to comprise the research program, (b) the level of financing for each project, (c) the marginal utility which could be derived from investing in extra units of resources for the research program and for each project, and (d) 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 (a) choosing research areas to work in and (b) choosing a research job portfolio. To analyze the first problem, he set up a nonlinear integer programming problem which made use of a staff preference function and information on (a) researcher time, (b) the amount of funds that new research areas would bring into the department, and (c) 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 decisionmaking (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 decisionmakers' preferences.13/ Thus, they were primarily positive, rather than normative techniques.

Conclusions Regarding Existing Methodology 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, especially for "basic" research, which diminishes the private incentive to invest in it. Governments have recognized these facts and have, as a result, invested substantially in the agricultural research process.

Diverse approaches have been employed over the past 25 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. Therefore, it may be useful to make some comparisons among the types of studies described and to draw conclusions about their strengths, weaknesses, and appropriateness for answering different questions. There are several relevant comparisons that could be made among research evaluation studies. Several of the major ones are shown in Table 1.

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 decisionmakers and quantify the tradeoffs among their goals. For this reason, the scoring model and mathematical programming approaches usually involve some elicitation of goals. Those methods can consider the tradeoff of goals, and provide a ranking of projects based on multiple goals. All research evaluation studies, however, deal implicitly, if not explicitly, with goals. Some 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. The consumer-producer surplus and the ex ante benefit-cost approaches are methods which can most easily provide this information.

The production function technique is the best one for examining effects of research on the relative productivity of input categories such as land and capital and, therefore, on their relative shares of income. Although few have accounted for secondary impacts such as displaced resources, environmental effects, or regional impacts, the consumer-producer surplus, ex ante benefit-cost, scoring model, and simulation approaches could be used for this. Schmitz and Seckler, for example, used the consumer production surplus approach and accounted for the impact of the tomato harvester research on labor displacement.

One must recognize the economic policies 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 appeared to be highly profitable. Trade and other economic policies can theoretically be included in every one of the approaches. The production function approach does it implicitly while the others must do it explicitly. If such policies are not considered when using these techniques, the results can be misleading.

It is evident from Table 1 that several alternative techniques could be used to answer certain questions. The choice of which if any of them to employ is therefore likely to be affected by their relative costs in terms of evaluator's time, administrator's time, and scientist's time. A quick look at these characteristics in Table 1 sheds some light on why the consumer-producer surplus, production function, and ex ante benefit-cost approaches have received the most widespread use as agricultural evaluation tools. There is, of course, one technique which does not even appear in the table and has received more use than any of the others, namely, sole reliance on the decisionmaker's subjective feelings about the merits of different types of research. Closely related to this are the subjective evaluations prepared for the decisionmaker describing in general terms what the research has accomplished and/or what it is expected to accomplish in the future. In an earlier review, Peterson (1971) called this the public relations approach. A major reason for using it is its low cost.

An important issue, then, is whether systematic or more formal analysis of benefits and costs can improve the decisionmaking process and, if it can, whether it is worth the cost. Some would argue that there is a large amount of serendipity or luck involved in research discoveries so it is meaningless to conduct an ex ante evaluation of how research resources should be allocated to maximize their payoff. Clearly, there is a danger of dampening incentives and creativity of researchers if research is "overmanaged." It is difficult to predict which projects will have the highest payoff using any of the techniques in Table 1. It may be possible, however, to use some of these techniques to increase the percentage of resources for given types of projects. This is perhaps more likely to be true for evaluations of applied than for basic research. The outcome of the latter is general knowledge, the relevance and value of which may not be readily apparent. Clearly, the ex post rates of return estimated by the consumer-producer surplus and the production function approaches have documented the general underinvestment in agricultural research. These results can be and have been used to support budget requests at the state and national level.

The described techniques vary in their data requirements. The production function technique requires a good deal of data in many cases although it is usually secondary data. The scoring model approach, on the other hand, requires little data, but the data come at a high cost since they are primary data.

Few studies have measured the value of maintenance research. This question probably could be handled most easily with the consumer-producer surplus approach. It could be argued that over time the maintenance of crop and livestock yields has increasingly become a larger proportion of total research benefits.

Evaluation of agricultural research occurs at the aggregate level, commodity level, and project or program level. The production function approach is of little use at the project or program level while the scoring model and math programming approach potentially have their most usefulness at that level. The latter two can also evaluate nonproduction-oriented or noncommodity research more readily than the others. The major problem with evaluation of noncommodity research including much of social science research is in defining and measuring the output. In general, the output is information rather than improvement in the quality of production inputs. There appears to be some potential for use of consumer-producer surplus

Table 1. Comparison Among Major Agricultural Research Evaluation Techniques

Characteristic	Ex Post Techniques*		Ex Ante Techniques*			
	CS	PF	SM	BC	SI	MP
1. Requires explicit elicitation of goals.	no	no	usually	no	no	yes
2. Can determine distributional effects on consumers and producers at various income levels.	yes	no	no	yes	yes	no
3. Can determine effects on relative productivity of input categories.	no	yes	no	no	yes	no
4. Can consider secondary impacts of research on employment, environment, nutrition.	some	no	yes	some	yes	no
5. Can consider tradeoff among goals.	no	no	yes	no	yes	yes
6. Can consider economic policy and trade effects.	yes	yes	yes	yes	yes	yes
7. Relative cost in researcher's time.	low	interm.	interm.	low	high	interm.
8. Relative cost in scientist time.	low	low	high	interm.	interm.	interm.
9. Relative cost in administrator's time.	low	low	high	low	low	interm.
10. Relative data requirement.	low	high	low	low	variable	interm.
11. Can consider value of maintanence research.	yes	no	no	yes	yes	no
12. Can evaluate benefits to "aggregate" research.	yes	yes	no	yes	yes	no
13. Can evaluate benefits to "commodity" research.	yes	yes	yes	yes	yes	yes
14. Can evaluate benefits to research projects or program.	yes	no	yes	yes	yes	yes
15. Can evaluate benefits to "non-production" or "non-commodity" oriented research.	In some cases	no	yes	In some cases	In some cases	yes
16. Can provide ranking of research projects based on multiple goals.	no	no	yes	no	no	yes
17. Can handle uncertainty.	with sensitivity analysis	with diffic.	yes	yes	yes	yes
18. Can consider the lags involved in research and adoption.	yes	yes	yes	yes	yes	yes
19. Can quantify public sector-private sector interaction.	no	no	no	no	no	no
20. Can quantify research-extension interaction.	no	some	no	no	some	no
21. Can quantify spillover effects.	no	yes	no	no	yes	no
22. Usually estimates marginal rate of return.	no	yes	no	no	sometimes	no
23. Usually estimates average rate of return.	yes	no	no	yes	sometimes	no
24. Calculates return while statistically holding nonresearch inputs constant.	no	yes	no	no	sometimes	no
25. Usually require computer.	no	yes	no	no	yes	yes
26. Can help identify or quantify factors most effecting progress in given research line.	no	no	yes	yes	yes	no
27. Can be used to evaluate basic research.	no	some	some	no	some	no

*CS - Consumer-producer surplus approach; PF = production function approach, SM = scoring model approach, BC = *ex ante* benefit-cost approach; SI = simulation model approach; MP = mathematical programming approach.

and *ex ante* benefit-cost analyses to quantify the returns to such research. There may also have to be other techniques employed which are very different from those used so far in agricultural research evaluation. Decision theory may have a role to play in this area.

Uncertainty can be handled with any of the techniques although it complicates considerably the production function approach. Lags can be considered in any of the approaches although a statistical determination of the appropriate length and shape of the lag is only an output from the production function approach. None of the approaches quantifies the public-private sector interaction nor does a good job of quantifying the research-extension interaction. Spillover of research from one area to another can be quantified with the production function and certain types of simulation approaches.

Not all of the studies involve calculation of a rate of return to research. A marginal rate of return can be readily calculated using the production function approach, while the consumer-producer surplus and ex ante benefit-cost analyses usually provide average rates of return. Only the production function and the simulation approach (if it involves regression analysis) statistically hold nonresearch inputs constant in the analysis.

While any of the methods could use a computer, the production function, simulation, and math programming approaches would be very difficult to use without one. Scoring models and simulation models as well as ex ante benefit-cost models if scientists are interviewed can be used to help identify and quantify factors affecting progress in given research lines. None of the methods do a good job of evaluating basic research.

The issues discussed and compared above indicate that while a rich set of evaluative procedures have already been developed, there is need for additional work.14/ It would appear that three areas greatly in need of further methodological work are (a) the evaluation of noncommodity research, (b) 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 (c) the importance of the private sector-public sector interaction in agricultural research including the transmission of research results to the farmers. The emerging literature on the value of information may be of assistance in evaluation of noncommodity research. Decision theory may prove useful in quantifying benefits in this area. Communication with physical scientists will be necessary for progress in the second area. Primary survey work may prove helpful in uncovering the private sector-public sector interaction.

Footnotes

1/ While it is true world expenditures on agricultural research have increased substantially over the past 25 years, aggregate expenditures on agricultural research in the United States have exhibited a very slow rate of growth over the past 10 years (Evenson, Waggoner, and Ruttan).

2/ An additional list of 135 categorized references not cited here that provide other examples of the techniques described is available from the authors.

3/ The production function approach 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 we treat them separately.

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

5/ This approach also has been called the index number approach.

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

7/ Grossfield and Heath 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.

8/ The change in producer surplus = $OABP_2 - OAH$. The change in consumer surplus = $P_2BC - P_3FC = P_2BFP_3$.

9/ Lindner and Jarrett use the term "inframarginal" to refer to the more profitable, lower average cost firms. Rose, however, points out that the rent component in supply price makes it difficult to link given firms with particular points on the supply curve.

10/ Linder and Jarrett (1978) have $A_1 = A_0(1-k)$, but Rose correctly points out that it should be $A_1 = A_0/(1-k)$.

11/ Williamson provides a good summary and evaluation of the report and the procedures used.

12/ Minnesota Agricultural Research Resources Allocations Information System.

13/ "Decisionmakers" refers to government officials at the state or national level and/or research administrators at the university or academic department levels.

14/ Other papers dealing with research spillover, social science research evaluation, and other evaluation issues and techniques are forthcoming in a proceedings of a recent symposium on research evaluation methodology (Sundquist, Norton, Fishel, and Paulsen).

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