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RESEARCH EVALUATION: POLICY INTERESTS AND THE STATE OF THE ART

Robert E. Evenson*

In 1969, the Minnesota Symposium on Agricultural Research brought together most of the people who had worked on the problem of evaluating returns to research. The impetus for that symposium did not come from policymakers who were anxious to utilize the methods for ex ante and ex post evaluation. It was organized as an academic gathering of the several scholars whose work in the previous several years was related to the economics of agricultural research. Now, some 11 years later, we are again convening at Minnesota. In these past 11 years interest in the evaluation of agricultural research activities has grown substantially. This is particularly true of the policy-oriented branch of this field, and policymakers have provided considerable impetus for today's symposium.

I take my task in this paper to be to attempt an evaluation of the methodological foundations that have been employed in the field. I will approach this by first developing a taxonomy of the branches of work that have taken shape in the past 20 or 25 years. This will allow a more organized discussion and provide a distinction between studies which contribute to the state of basic understanding of research activities and studies which concentrate on providing policy calculations. I will conclude that almost all of the policy-oriented work is based on the state of understanding of the research process that we had attained 11 years ago. I will also conclude that some significant advances have been made in terms of our understanding of what research is and what research effort produces. We know enough to treat different types of research and extension as producing different things. We also know how they are related.

Perhaps the area where we have gained most in the past 11 years is in our understanding of genotype-environment interactions and their influence on technology transfer. Much of this knowledge has emerged from the international studies in the field. We have also made advances on two other fronts. We know more than we did 11 years ago about the public sector demand for research mechanism. We also know more about how to evaluate systematically all, or at least most, of the economic outcomes of a research program.

Evaluation Objectives and Methods

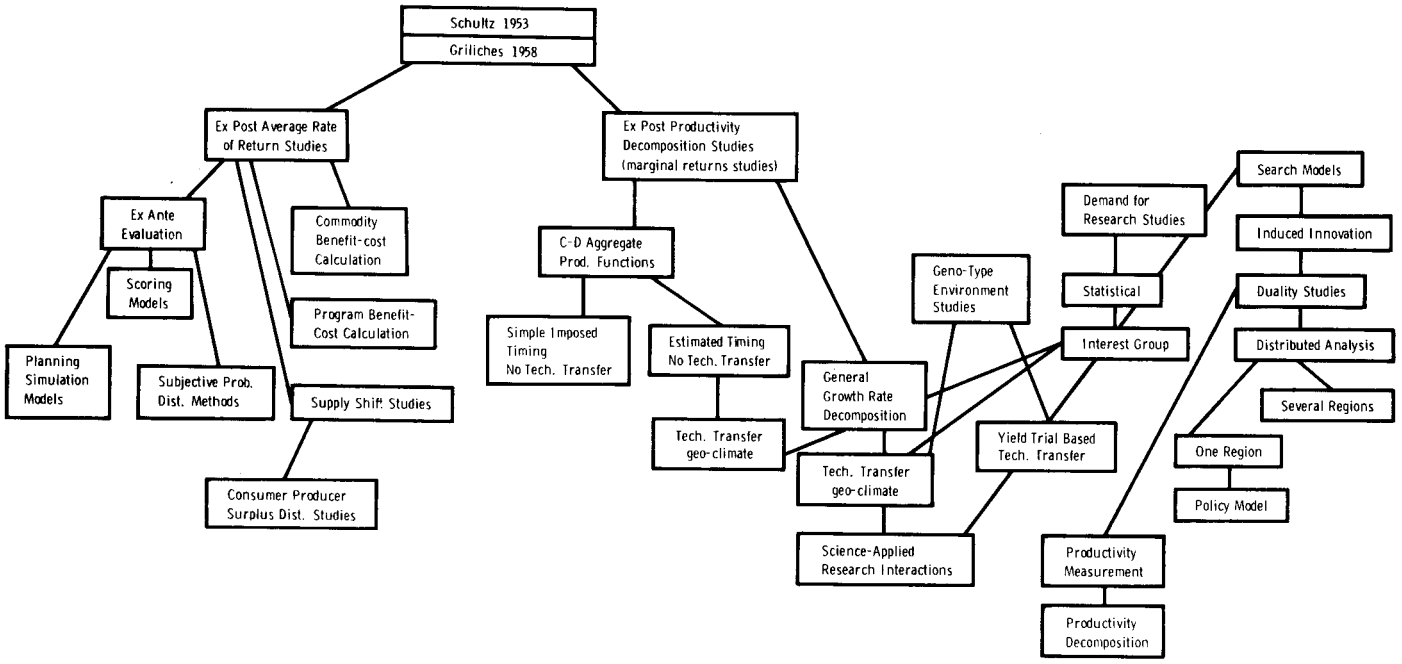
The paper by Norton and Davis for this conference provides a useful review of most of the relevant literature. They identify two ex post techniques, consumer-producer surplus analysis and production function analysis; and four ex ante techniques, scoring models, benefit costs, simulation models, and mathematical programming. I find a modified description of techniques and methods useful. Figure I provides a tax on any of my techniques which I have arranged in a historical context.

In Figure I, I acknowledge the seminal contribution of Schultz and Griliches and identify two basic lineages stemming from this work. The first significant body of work to emerge was the ex post average rate-of-return studies which basically used the Griliches corn study as a model. It is of interest to note that many such studies are still being conducted. They have not grown significantly in sophistication. The basic methodology requires identifying the shift in the supply function attributable to a research program. The recent debate over the nature of the supply curve shift (Lindner and Jarrett) has added some new variables here. I am also including the simple distributional studies which attempt to identify only changes in producers' and consumer surpluses to this lineage.

As I see it, most of the ex ante studies have essentially grown from this basic lineage. Ex ante questions are generally average rate-of-return questions. Scoring models probably preceded the rate-of-return studies but were given more credence after these studies were done. The applications of subjective probability distribution methods to ex ante research evaluation was a natural extension of the decisionmaking literature. Some planning and simulation models are included in this branch even though they are not serious ex ante methods. A number of sectoral policy models, designed to illustrate

*Professor, Economic Growth Center, Yale University.

Figure 1. Development of Research Evaluation Methodology



possible economic outcomes from research programs have been developed. They may tell us something about different effects of research given that one knows what the research program is likely to produce but are not suited to real ex ante evaluation. (I also include other policy models in the right-most branch, but these are simpler duality models also not suited to ex ante evaluation).

The second main branch of the literature has been in the productivity decomposition line. This work differs from the first in two major dimensions. First, it is statistical and thus requires some kind of model structure. Second, it is suited only to a marginal rather than an average rate-of-return calculation. Much of this literature has used a simple (and somewhat pedestrian aggregate Cobb-Douglas production function approach). One sub-branch of the literature (still underway) imposes rather than estimates the timing of spatial dimension of the research impact. Another sub-branch does attempt to estimate the time-shape of the research effect on production. We begin to see the influence of theorizing about the research process in the early estimates of the time-shape and of technology transfer. The definitions of geoclimate regions and of "borrowable" research stocks moved this research out of the simple Cobb-Douglas model (even though at first it continued to use this functional form). The search model development moved the work toward making clearer distinction between applied technology-oriented research and related science.

A related line of work on public demand for research emerged in the late sixties, but it has, to date, had relatively little influence on the productivity studies. In an effort to move to more meaningful functional forms, some studies have gone to a growth rate specification.

Recent conceptual work on technology transfer has clarified some of the issues associated with genotype-environment interactions and breeding for adaptability. A new literature on the economics of breeding is emerging, and while it hasn't influenced much of this literature, it promises to do so in the future.

I have shown what amounts to a new lineage in the right-hand side of the figure. This is the induced innovation-duality-based literature which promises to allow us to measure factor market outcomes of research directly. It is also suited to analyses of differential effects of research outcomes among different types of farmers producing the same or similar products.

Having presented this sketch, let me now offer some further observations:

1. The sketch and the Norton-Davis review indicate that the literature has little to say about (a) post farm harvest research-marketing-processing; (b) economic and social science research; and (c) the effect of private sector research.

2. Most of the policy-related literature--specifically the ex ante literature--has not been influenced very much by the relatively small theory literature which can be said to have been inspired by the problems in the field. This is partly due to the inherent difference in approach by the policy-oriented researcher and the economist interested in a better understanding of the broader process of economic growth.

3. The theoretical and econometric level of this field, in general, has been rather low. Perhaps because it has grown slowly, we haven't had a lot of pressure to "do it right." In other areas of study, we would not have gotten by with the excuse that public spending decisions on research were exogenous or that we did not have to worry about spillover.

Bringing More Theory to Evaluation

Two basic questions are posed to me by my taxonomic review:

(1) Is it possible to bring more of the theoretical developments, such as they are, into the policy literature?

(2) Can the literature address a broader range of issues and provide us with a better understanding of the growth process?

In addressing the first question it is important, I think, to make a distinction between policy questions associated with the evaluation of particular research projects or programs (sets of related projects) and broader issues of research organization, environment, and management. Much of the research project or program evaluation literature takes as given the research environment and organization. It also takes as given the quality of the research staff. Yet, in a longer run context, the design of the experiment station system, the entrepreneurship of researcher, environment in which researchers work and the skills of the researcher are probably at least as important as the specific projects that researchers work on.

Policy-oriented studies, particularly the ex ante studies, have little to say directly about these issues. Ex post studies, particularly those employing a transfer specification, do provide some guidance, but the ex ante branch of the literature appears to me to have made little or no methodological progress beyond Walt Fishel's work reported at the Minnesota symposium 11 years ago. I felt at that time that the method had a lot of promise and that policymakers would find the variances of the estimated benefit-cost ratios produced by Walt Fishel to be valuable. As I understand the developments in the past 11 years, policymakers really haven't found the variance measures very useful or haven't understood them very well. What they have found useful is the relatively high benefit-cost ratios produced by these exercises.

Unfortunately, most writers in this field have found their results used in various ways to support more research, some of which doesn't deserve support. The ex ante methods are particularly vulnerable to this policy "corruption" because they must rely on self-interested information sources. Every experiment station director and almost all scientists have vested interests. They cannot be avoided. Economists in these systems also have vested interests.

My reading of the ex ante literature suggests that, at best, the numbers generated can enable a rough ranking of projects and programs. I have elsewhere argued that, in the long run, nature is likely to be fairly "plastic" in yielding her secrets to research. That is, that the probability of a particular unit cost-decreasing discovery doesn't vary much across different commodities. This seems to be supported by the ex ante studies, but I doubt that it is. I am afraid that most scientists are simply biased toward the notion that a certain gain may be expected from a project.

We know that many research projects ex post produce little. We know that certain research institutions are more productive than others and that great variations in the output of individual researchers exist. We also know that professional research project proposal writers abound and that few research funding units actually do much ex post project evaluation. Agricultural experiment stations tend to have a number of ongoing service type projects, many of which haven't had an input of any imagination for years. Civil service and tenure systems protect the unproductive researcher and may militate against good work. Advances in science may render many research skills obsolete.

I am not suggesting that these factors necessarily make ex ante methods which do not take them into account worthless. I am convinced that a broad range of research outputs have value. Not all of them necessarily result in published output or high peer recognition. Experiment stations do have to maintain some service type work and extension work.

These considerations argue against extensive use of ex ante methods for finely tuned evaluation. This is particularly true if the employment of the methodology impedes real research. Even the project proposal system is restrictive to a productive researcher who requires flexibility to pursue hunches and to change direction in mid-stream.

Ex ante evaluation ultimately requires two numbers, a probability of output increase or unit cost decrease and an estimate of the number of units over which the improved technology can be employed. Both are difficult to measure.

The number of units over which improved technology can be used requires an understanding of technology transfer. Ex ante methods have been slow to build technology transfer specifications into their work. New soybean varieties of a particular maturity range, for example, are transferable only over a certain geographic area and their degree of superiority over existing varieties is not constant over that area.

There is also some scope for effective use of ex ante information in economic policy models. A very sharp distinction between the large "black box" simulation models where estimates of parameters and functions are not systematically made and the small simple consistently estimated simulation model should be drawn here. The track record of the black box models is not good even as regards the simulation of well-understood policy changes (such as prices). The small duality-based models with a consistent set of estimates have more promise. These models, however, can only translate ex ante research product estimates into estimated economic outcomes. They are not useful in terms of producing better ex ante estimates.

The ex post literature has also been subject to policy corruption of the same sort which influences the ex ante works. The statistical setting of many of these studies provides some protection, but as we all know there are a number of alternative specifications of statistical specifications. As I noted earlier, this branch of the literature has made some forward progress in terms of being influenced by the three or four minor developments in theory. (Many studies underway at the present time, however, have not done so--the old Cobb-Douglas model which makes no attempt to estimate the time shape or to incorporate technology transfer, is still in use. This attests to the serviceability of the model, but there are better alternatives.)

In terms of policy influence, I would think that the ex post literature has had much more influence than the ex ante literature. In a recent policy paper, Vernon Ruttan, Paul Waggoner and I (1979) saw fit to report some 35 or so ex post estimates of average and marginal rates of return to research.

The fact that a large number of studies using different methods studying different research programs on different commodities and in different countries has produced estimates with the degree of consistency of these studies is impressive. Ex ante studies have influenced project selection to some extent, and this is where they are appropriate. Efforts to pass them off as though they were ex post studies are not appropriate. We have little direct evidence regarding the consistency of ex post and ex ante studies, but it seems quite likely that most ex ante studies have a serious upward bias.

These studies have probably influenced policymakers internationally more than domestically. They have also suggested some of the organizational reasons for effectiveness of research, particularly regarding the role of client demand articulation on the system. They have also stimulated a number of criticisms of agricultural research and of the way that agricultural research programs are evaluated. Some of these criticisms are not very telling, others are. The literature has not yet responded to them very well.

In organizing the remainder of my discussion, I will first discuss the four bodies of new theory that impinge on this work. In the final section, I will turn to some of the matters raised by our critics.

Advances in Theory and Evaluation

A. Search and Induced Innovation Concepts

The search model has been applied to the research process in a pretty ad hoc way, but it has at least served to illustrate the exhaustion phenomenon which affects all research. (Kislev and Evenson, 1976). It has also shown how different specializations among researchers can be productive. The contemporary agricultural research system has been fairly effective in institutionalizing research specialization with the station institution. The research projects and activities at a typical state experiment station range from very practical field testing projects to highly scientific work in plant physiology or pathology. Most of the evaluation studies do not attempt to distinguish between these different types of research. Yet the long-term success of a research program may depend on the mix of research projects and the capacity of the technical researcher within the program to signal the nature of his problems and limitations to the more basic researchers. Of course, research projects do not necessarily have to be closely integrated to complement one another. A project in one station can and does stimulate researchers in another. One of the reasons why the state and regional stations have been productive is that they have created what, in effect, are technology-oriented disciplines within much of the agricultural sciences. These "hybrid" research programs can take advantage of the strengths of each orientation.

A strictly mission-oriented research organization is generally highly dependent on other institutions for the creation of research (or search) potential. Many mission-oriented programs go through a stage of highly productive exploitation of potential discoveries and then reach a state of exhaustion. If they lack the capacity to create new potential or to influence others to create it for them, they remain

unproductive no matter how important their mission and qualified and dedicated their researchers.

A strictly disciplinary research organization, on the other hand, relies heavily on peer review standards and has the capacity to impose a high level of structure and rigor to a problem. Disciplines also develop subfields and subdisciplines which allow research efforts to be channeled in directions with high scientific promise. The value of the outputs of a disciplinary research organization depends on the degree of demand pressure placed on it. If no demands in terms of particular kinds of studies of value to mission-oriented researchers are placed on the system, it will be guided strictly by the scientific opportunism inherent in the discipline. It will produce some knowledge of value to the mission-oriented researcher but it may be very costly to implement.

When mission-demand pressure is imposed on a discipline, it loses some of its capacity to produce knowledge, but it may produce more valuable knowledge which can be more easily converted to technology potential by mission-oriented researchers. Research program evaluation methods generally have not been very sensitive to this issue. They have tended to treat the projects with technological products as one class of projects and those without technological products as another class.

Productivity decomposition studies have attempted to address this by defining a technology-oriented research stock and a science-oriented research stock with some success. We have, however, very few studies of this type. The richness of the research data for U.S. agriculture should allow us to do much more than we now do. A related question is that of "maintenance" research. We recognize the usefulness of this research, but do not really have an effective way of evaluating it.

Suppose we have a research program with a maintenance component, a technological research component, and a mission-discipline scientific component. Do we have an evaluation methodology rich enough to allow us to assess whether the right mix of these activities is being achieved? One could construct three research stock variables, each with different time dimensions and utilize interaction terms in a productivity decomposition model. Alternatively, one could attempt to build the maintenance research into the timing dimensions of the research variable. The difficulty here is that we have both real and obsolescence effects to deal with. Maintenance research does not affect obsolescence. With sufficient data, variable lag estimators might be used to sort out the maintenance effect.

B. Technology Transfer Issues

Everyone recognizes that productivity growth in a particular state or region is determined not only by the research investment in that state or region but also by technological improvements developed elsewhere which "spillin" to the state or region. Even in cases where no direct technology transfer is involved, the research productivity of a given state is affected by developments in other states. It is thus very easy to make errors in the attribution of productivity gains to a particular state. For the "average" state, spillins are approximately equal to "spillouts," and in a left out variable sense this may mean that no serious bias in the standard production function approach exists. This, however, does not hold for all states and one certainly would not wish to compute state-specific marginal products without a more reasonable specification.

The geoclimate regional specification which has been employed in some studies is a pretty serviceable one provided one uses it with care. Appendix 1 reports some previously unpublished results obtained in a study done some years ago by Finis Welch and myself. It illustrates one technique for dealing with spillover.

Recent work utilizing yield trial data now allows us a richer possible specification. (See A. S. Englander's paper in this symposium.) This essentially amounts to calculating a transfer gradient between any two locations i and j from data on crop yields in the two locations. A borrowable research stock can then be computed by using these transfer gradients as weights in summing up research done in other regions.

The technology transfer literature has its own policy relevance in terms of optimal experiment station location and optimal targeting of research to environments.

C. Demand for Research Studies

The issue of the public demand for investment in research programs is an interesting topic in its own right. The question at hand, however, is whether the productivity and other effects of research programs can be analyzed without a formal treatment of the simultaneity problem. Is the research stock variable a reasonably exogenous variable in the statistical analyses? It is not if state political systems are responding to productivity performance of the agricultural sector in their investment programs. We have relatively little work on this topic, but with recent studies of the demand for research as a public good, it should be possible to produce more estimates using simultaneous equation procedures. (Unfortunately some of the studies of

the public demand for research themselves suffer from simultaneity).

Recent work by Huffman and Miranowski (1979) and Rose-Ackerman and Evenson (1980) is of relevance here. These studies generally find that economic variables such as output and farm income are determinants of state research spending. The evidence as to whether productivity change is a determinant is less clear. Huffman, in a recent paper on extension impacts, shows that the estimated extension impact on productivity is substantially higher when simultaneity between schooling of farmers and extension is considered.

D. Distributional Models

Many state experiment station researchers take the position that they have an interest in serving their clientele well. This is not unreasonable since they are supported primarily by state producer groups. If this is the case, the question of research spillover takes on special importance. Producer groups in a specific region have an interest in producing group-specific technical change. This is easily seen in Figure 2 where we have two groups of suppliers producing the same product. S_{10} is the supply of group 1, $S_{10} + S_{20}$ the aggregate supply of both groups. Initial price is P_0 and region supplies S_{10}, region 2 $S_0 - S_{10}$.

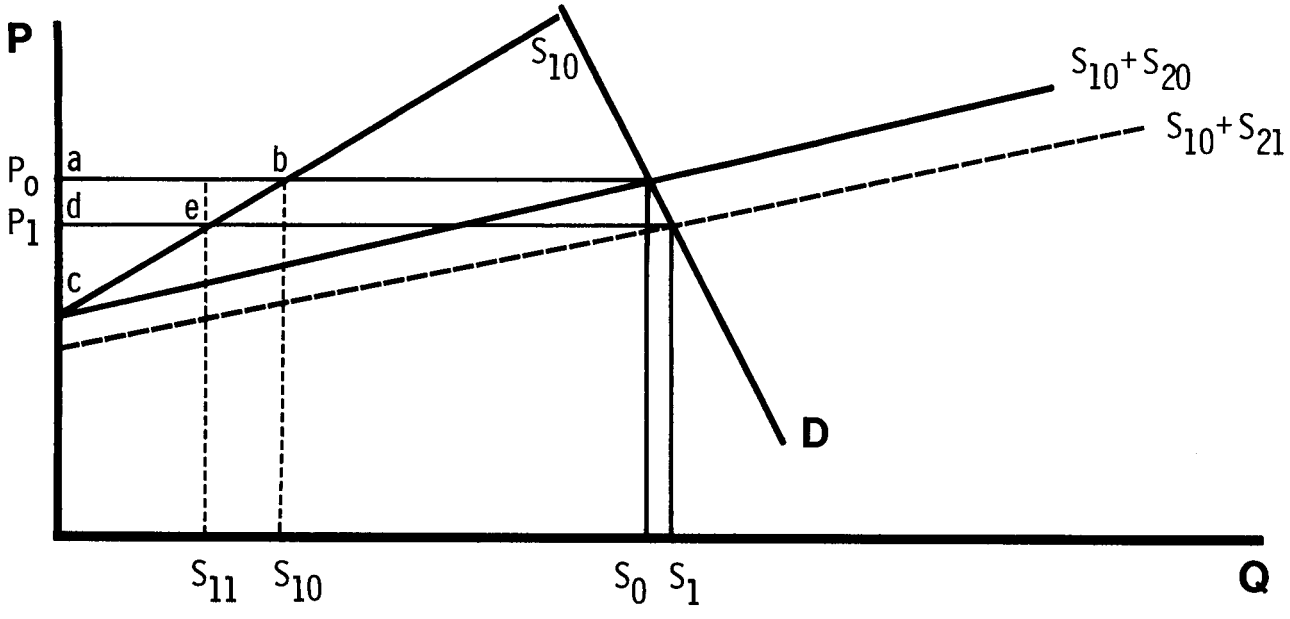
Now, suppose that research results are available only to group 2 producers. This will shift the aggregate supply curve to $S_{10} + S_{21}$. Market price will fall to P_1 and group 1 suppliers will cut back their supply to S_{11}. It is quite clear that they lose in the process. Rents to fixed factors to producers in group 1 unequivocally fall (the area abde). Rents to producers in group 2 may increase (depending on the elasticity of demand). Variable factors will be affected differently in the two groups only if they are immobile. Farm workers are not that mobile, however, and they may suffer a reduction in demand (and in wages) in group 1.

This model has many more aspects to it and I am attaching an Appendix 2 dealing with it. Here I want simply to make the point that if you are evaluating this research from the point of view of the group 2 producers, you have to acknowledge that if the technology is transferred to group 1 producers, it will not only raise rents to group 1 producers, it will lower them to group 2 producers. Conversely, in group 1, if research projects can take advantage of the developments in group 2, they will clearly gain.

It is fairly apparent that a system of state producer groups has an interest in supporting parochial research projects. State producers are not anxious to diffuse technology to another state or region. They are, however, anxious to "borrow" as much as they can from the other region.

The argument holds for simple commodities and for commodities which are reasonably close substitutes such as different feed grains or oilseeds.

Figure 2.



These considerations affect the types of research projects undertaken and probably produce some duplication of research. Perhaps more importantly, however, they force research entrepreneurs to orient research to the interest of the clients.

In the developing countries, there is considerable interest in the effect of technology on the demand for labor and on employment and wages, but this is primarily generated by international policymakers and economists, not by any real political interest group. It appears unlikely on the basis of U.S. experience that agricultural labor will ever be a strong political force anywhere. Nonetheless, labor and farm families generally have been affected markedly by shifts in the supply (and demand) of agricultural commodities, much of it related to agricultural research. I will take this question up in the final section.

E. Duality Models

Appendix 2 derives a system of output-supply and input-demand functions for analytic purposes. These systems are well suited to research evaluation. The general procedure is to derive them from a profit function. Systems of output-supply and factor-demand equations could exist independently of the behavioral mechanism of profit maximization, as long as the behavior of individual agents is sufficiently stable over time and can be aggregated over farmers. Therefore, the estimated equations are useful for economic analysis regardless of whether the theory restrictions of profit maximization hold. However, if profit maximization does not hold, we cannot make inferences from the supply and demand equations about the production function underlying them since behavioral and technological relationships are then confounded in those equations.

To see the usefulness of this approach for research purposes, consider the following model. Suppose there are n commodities, Y_i, of which the first q are outputs and those indexed $q + 1 \ldots n$ are variable inputs under the control of the individual agent, i.e., we have a vector of commodities Y such that

$$(1) \quad Y_i \geq 0 \text{ for } i = 1 \ldots m \text{ and } Y_i \leq 0 \text{ for } i = m + 1 \ldots n.$$

These commodities have prices $P_i \geq 0$ for all i. Π is variable profits or return to fixed factors of production and $\Pi = Y'P$. Since inputs are negative quantities, they subtract from revenues of the positive outputs. There are also k fixed factors of production, Z_k, $k = 1 \ldots k$ such as land, fixed capital, or land quality. Let t stand for a technology index which is related to a research variable. If a sufficiently "well behaved" transformation function1/ exists, $g(Y,Z,t) = 0$ and agents maximize variable profits Π, then a profit function exists which relates maximized profits Π^* to the prices of the variable commodities, the fixed factors and technology.

$$(2) \quad \Pi^* = \Pi^*(P,Z,t)$$

which has the following properties (where Π^*_i and Π^*_{ij} are derivatives of the profit function with respect to the subscripts.)

(i) The profit function is monotonically increasing in P if it is an output price and monotonically decreasing in P if it is an input price. The output supply and factor demand curves are

$$(3) \quad Y_i = \Pi^*_p(P,Z,t) \begin{cases} \geq 0 & i = 1,\ldots m \\ \leq 0 & i = m+1,\ldots n \end{cases}$$

(ii) The profit function is symmetric, i.e.,

$$(4) \quad \Pi_{ij} = \Pi_{ji}$$

(iii) The profit function is convex, i.e., the (singular) matrix of its cross derivatives Π_{ij} is positive semi-definite or all its characteristic roots are positive or zero.

(iv) The profit function is homogeneous of degree one and the supply and demand equations are homogeneous of degree zero. The matrix

$$[\eta_{ij}] = \begin{bmatrix} \frac{\partial Y_i}{\partial P_i} \frac{P_j}{Y_i} \end{bmatrix}$$ defines the factor demand and output supply elasticities and the following constraints hold:

$$(5) \quad \sum_{j=1}^{n} \eta_{ij} = 0$$

Table I shows the output supply and factor demand curves for three "flexible" functional forms. The transcendental logarithim profit function has the form

$$(6) \quad \Pi^* = a_o + \sum_i a_i \ln P_i + \tfrac{1}{2}\sum\sum_{ij} b_{ij} \ln P_j + \sum\sum_{ik} b_{ik}(\ln P_i)(\ln Z_k) + \sum_i b_{it}(\ln P_i)t$$

Its output supply and factor demand curves are given in panel (a) of Table 1 where s_i is the share of an output (input) in variable profits. Note that shares of inputs are negative. Equation (b) in Table 1 gives the system of equations when the homogeneity in (c) is imposed, while (A) does not impose the constraint. In estimating (A) or (B) one leaves out the i'th equation because it is not independent of the remaining shares equations since shares add up to zero. If the number of factors is not too large, one can estimate the system of shared equations jointly with the profit function (6). Convexity has to be tested by computing the characteristic roots of Π_{ij} which in turn can be computed from the η_{ij} matrix. The generalized Leontief function is written as

$$(7) \qquad \Pi^* = \sum\sum_{ij} b_{ij} P_i^{\frac{1}{2}} P_j^{\frac{1}{2}} + \sum\sum_{ik} b_{ik} P_i Z_k + \sum b_{it} P_i t$$

The corresponding factor-demand and output-supply system is given in panel (B) of Table 1. All equations of (A) can be estimated jointly but the profit function is not linearly independent since it is the linear combination $\sum_{i=1}^{I} Y_i P_i$ of the individual equations. Note that in this system, homogeneity is not testable since for each equation η_{ii} is estimated residually and we have no other independent estimates of it.

The third functional form is derived from the normalized quadratic profit function. For a discussion of normalized profit functions, see Lau, 1977. A normalized profit function is derived by stating the initial profit maximizing problem in terms of normalized prices $q_i = \frac{P_i}{P_n}$ where all prices and profits are divided by the price of the n'th commodity. Normalized profits then is written as

$$(8) \qquad \bar{\Pi} = \frac{\Pi}{P_n} = \sum_{i=1}^{n=1} Y_i q_i + Y_n$$

Shepherds Lemma then reads that $\frac{\partial \bar{\Pi}}{\partial q_i} = Y_i$. The quadratic normalized profit function is written as

$$(9) \qquad \bar{\Pi}^* = a_o + \sum_{i=1}^{n-1} a_i q_i + \tfrac{1}{2} \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} b_{ij} q_i q_j + \sum_{i=1}^{n-1} \sum_{k} b_{ik} q_i Z_k + \sum_{i=1}^{n-1} b_{it} q_i t$$

The factor-demand curves for the first n-1 factors are given in panel C of Table 1, written in terms of the original prices. Homogeneity of degree zero is imposed on the equations and cannot be tested. Symmetry is tested in the usual way.

The relevance of this model for research evaluation is that the research "stock" variable can be included in each equation in the system. One can then directly estimate the marginal impact of a change in the research variable on the supply of outputs and the demand for variable factors.

Comments on Other Criticisms of Research Evaluation

The agricultural experiment station system is not without its critics. I will discuss three main charges:

1) That modern agricultural practices have created an ecological nightmare. Genetic vulnerability, soil and water pollution (and scarcity), loss of forest cover, loss of wildlife and natural plant species are all laid at the doorstep of agricultural research.

2) That agricultural research institutions have politically allied themselves with, or have become the captive of, the large agribusiness firms in their war with family farms and farm labor. They have produced and promulgated technology suited to the large farms of the agribusiness firm.

3) That agricultural research has produced severe labor market dislocations through the rate of technical change and the labor-saving bias in technical change. Farm laborers, farm families, and whole farm communities suffered damages as a result. Some form of compensation should be included in rate-of-return estimates.

It is tempting to dismiss the ecological nightmare argument by noting the flaws in the argument. Surely, had less agricultural research been done in the United States over the past century, we would be using more water and land resources, not less. We would have very severe water resource problems and more pressure on forests and wildlife. The notion that agricultural research and the use of farm chemicals has resulted in depleted soil resources is not generally true. Most midwestern farmland is probably more fertile today than it was in its virgin state.

Nonetheless, the water pollution arguments from farm chemical runoffs have some validity and the same is true for possible health consequences of chemicals. It is easy to overstate these costs, however. The regulations and restrictions imposed by EPA, OSHA, and other agencies reflect an irrational degree of risk aversion on the part of the government. They initially pose high costs, but these costs have been lowered as a result of agricultural research

Table 1: Formulas and Tests.

	a Translog	b Generalized Leontief	c Normalized Quadratic
Demand	(A) $S_i = a_i + \sum_{j=1}^{n} b_{ij} \ln P_j$	$Y_i = b_{ii} + \sum_{j \neq i} b_{ij} \left(\frac{P_j}{P_i}\right)^{1/2}$	$Y_i = a_i + \sum_{j=1}^{n-1} b_{ij} \frac{P_j}{P_n}$
Supply Curves	$+ \sum_k b_{ik} Z_k + b_{it}\, t$	$+ \sum_k b_{ik} Z_k + b_{it}\, t$	$+ \sum_k b_{ik} Z_k + b_{it}\, t$
	(B) $S_i = a_{io} + \sum_{j=1}^{n-1} b_{ij} \left(\ln P_j (-\ln P_n)\right) + \sum_k b_{ik} Z_k + b_t\, t$	$i = 1,\ldots,n$	$i = 1,\ldots,n-1$
	$i = 1,\ldots,n-1$		
Homogeneity	(C) $b_{in} = -\sum_{j=1}^{n-1} b_{ij}$	Imposed, not testable	Imposed, not testable
Symmetry	(D) $b_{ij} = b_{ji} \quad i \neq j$	$b_{ij} = b_{ji} \quad i \neq j$	$b_{ij} = b_{ji} \quad i \neq j,\ i \neq n$
Elasticities			
Cross price	(E) $\eta_{ij} = \frac{b_{ij}}{S_i} + S_j$	$\eta_{ij} = \frac{b_{ij}}{2Y_i} \left(\frac{P_j}{P_i}\right)^{1/2}$	$\eta_{ij} = b_{ij} \frac{P_j}{Y_i} \quad i \neq j,\ i \neq n$
Own price	(F) $\eta_{ii} = \frac{b_{ii}}{S_i} + S_i - 1$	$\eta_{ii} = -\sum_{j \neq 1} \frac{b_{ij}}{2Y_i} \left(\frac{P_j}{P_i}\right)^{1/2}$	$\eta_{ii} = b_{ii} \frac{P_i}{Y_i} \quad i \neq j,\ i \neq n$
			$\eta_{nj} = -\frac{P_j}{P_n^2 Y_n} \sum_{i=1}^{n-1} b_{ij} P_i$
			$j = 1,\ldots n-1.$

efforts to develop substitute technology. One might fault the agricultural research system for not itself being more "public minded" or anticipating the regulatory movement and perhaps influencing more reasonable regulatory behavior. The system, however, is basically supported by farmers, not consumers and farm laborers. We should not expect it to be fully public spirited.

In a large program evaluation, I would think it reasonable to regard the research to lower the cost of regulatory action which was induced by technology as part of the maintenance function of research. The regulatory environment, especially the present one, erodes the value of technology just as the disease and insect environments do. At the same time, a research system which is responding to farm interest groups' pressue may require some legitimate regulatory response.

The second charge that agricultural research is in bed with agribusiness and not interested in the family farm has a certain amount of truth to it. As I have noted, producer groups generally support research and if the average size of the producer or the form of ownership changes, it is not obvious that the public agricultural research system should abandon its old constituency and try to form a new one among family farmers. I recall the policy discussions of 20 years ago where economists were pointing out that even though average farm size had increased substantially in the prior 30 years, U.S. agriculture was still basically a family farm enterprise system.

These past 20 years have seen further change in the organization of U.S. agriculture. Average farm size has grown further and corporation farming has increased in importance, particularly in certain states. The model Midwest farm may still be a family farm, but this farm is now a larger unit. Almost any farmer who has owned land, even a relatively small farm, is now in the top 1 or 2% of the family wealth distribution in the United States. Many are in the top one-fourth of 1%. Yet the family farm mystique survives. This year's high interest rates and price situation brings the familiar pleas for taxpayer assistance to the struggling yeoman farmer preserving the virtues of rural life.

The agribusiness sector, both producer and marketing, has long managed to benefit from the family farm image. They form a natural political coalition with large farmers. Has the agricultural research system created this situation? Should it try to develop a small farm constituency?

The induced innovation model would say that with rising prices of farm labor, the nature of technology produced by both public and private institutions would be laborsaving. Most of the technical change which is at the bottom of the move toward larger units has been developed by private sector research not public sector research. Mechanical technology has been almost entirely developed in the private sector. In spite of the popularization of the tomato harvester and perhaps the cranberry harvester, it remains the case that the agricultural engineering research of the public stations has been weak. It has also been generally biased toward the small farmer, partly because it is somewhat out of date.

The increase in size of the power unit and consequently of harvesting equipment, the investment credit and the favorable farm prices in the 1970s created incentives for massive capital investment and rescaling of farm size. The public system did little to encourage or discourage this. As a public institution, it has to serve a clientele. And its natural clientele is probably the one that it is serving now.

The third criticism is related. Because new technology has resulted in a drastic reduction in the demand for farm labor (family or hired), over the past 50 years, a great deal of migration from agricultural occupations to urban occupations and from rural to urban areas has taken place. Should we not be including compensation for losses suffered by these migrants in our calculations? If so, the costs associated with migration have to be compared with these costs in other sectors of the economy. After all, even with large rural-to-urban migration flows, we have also had large urban-to-urban flows and regional flows. Farming is probably one of the more stable occupational patterns in the economy. The rate of turnover in restaurants and many retailing establishments is very high. Surely if we attempted to provide everyone with the right to a particular job, we would pay a cost that this economy would consider exorbitant.

It is unwise, in my judgment, to utilize arbitrary compensation schemes of the type posed in the tomato harvester study for evaluation. If one is serious about this we should be measuring the general age-specific costs of job-changing. How much specific human capital is lost? What is the value of the new opportunity? Actually, we would find that for many young people migration out of the sector was strongly preferred to staying. A premium would have been required to keep a large part of the labor force in agriculture. Contrary to the romantic urban academics, rural life has its disadvantages and even with high farm incomes, some migration would have taken place.

It is also a little difficult to argue that the costs of farm programs should be included in returns to research calculations. Alternatives to existing farm programs which should have cost a great deal less existed and were well known. The acreage restriction type programs actually utilized had high costs to be sure and in some sense are part of the costs of economic growth. But they could have been much lower.

Appendix I

The Pervasiveness of Crop and Livestock Research

The question of the pervasiveness of research, through time, space and among researchable problems and producers of agricultural product or consumers of the research product is at the heart of any empirical attempt to measure impact or to estimate profitability of research investments. In a previous study by Evenson, (1968), estimates of the time dimension of research impact were made based upon time series aggregates and the 1959 cross-sectional Census data. Taking advantage of the considerable detail afforded by the 1964 Census data, we now turn to the question of geographic pervasiveness. We have invoked but not tested in any systematic fashion an alternative mode for accounting for dimensions of pervasiveness among users of the research product and among research problems.

The factor motivating this approach to the 1964 data is that research expenditures can be segregated among crop and livestock commodities. We think it likely that livestock-oriented research has an impact over broader geographic areas than crop research and that the amount of spillover of effects of livestock research on

crop production and vice versa is slight. Thus, as noted earlier, the primary purpose for distinguishing the crop and livestock activities in specifying the aggregate relationship is to provide a basis for ferreting out the separate impacts of crop and livestock research. Our estimates focus primarily on the question of the geographic extent of the research impact. The related question of the timing of the response is not as efficiently addressed in cross-sectional as in time-series data, so we impose the inverted-V form of the lag function using research measures for the 13 years, 1951-1963, and a mean lag of seven years. This is based on the form identified in the estimates based on the earlier study.

In the earlier work on the 1959 data, Evenson experimented with constructs based upon contiguity. For example, the index of the research impact in state j was based upon an average of the form:

$$R_j = E_j + \theta_1 \sum_{i=1}^{N_c} E_i + \theta_2 \sum_{k=1}^{N_{cc}} E_k$$

with $1 > \theta_1 > \theta_2$. In this form, E refers to past values of publicly sponsored agricultural research expenditures accumulated over some distributed lag function in a particular state. The first term of this index refers to expenditures within the state in which impact is to be assessed, the next term is total expenditures in the N_c states having a boundary in common with state j and is given weight θ_1, while the third term includes total expenditures in the tier of states that are one state removed from state j and this aggregate expense is given weight, θ_2. In regression analysis using alternative values of the pervasiveness weights, θ_1 and θ_2, Evenson found that statistical results using only E (i.e., $\theta_1 = \theta_2 = 0$) were usually superior to alternative constructions.

A number of studies in recent years by economists and agronomists have established clear relationships between the economic superiority of a given technology and environmental factors.2/ A substantial number of agronomic studies of genotype-environment interactions have identified the degree to which the performance of a given crop variety changes under different environments.3/

An international study of wheat and maize productivity changes by Evenson and Kislev (1974) utilized geoclimate regions to identify the scope for technology borrowing or transfer between regions. We have developed a similar approach here. Figure 2 shows the delineation of 16 agricultural geoclimate regions for the contiguous United States. These were constructed primarily from work reported in the 1957 Yearbook of Agriculture. Within each region, from two to six subregions are defined. (See Appendix map.) The index of research impact used in this study is a simple variant of the index described above where pervasiveness is based upon contiguity, except that reference is either to "similar" regions or subregions.

Data for research expenditures are, of course, not provided for either regions or subregions but are state based. Our approach is to prorate research expenditures among the subregions within each state, using the geographic distribution of revenues as a basis. Data are available to permit rather straightforward allocations of research expenditures to 24 commodity-based categories. These include five classes that are allocated to research on individual kinds of livestock production (beef, dairy, hogs, poultry, and sheep) and a sixth category of general livestock research that could not be allocated to the specified classes and is therefore dubbed as "basic." Similarly, there are 16 specific categories of crop research that can be allocated to individual commodities,4/ plus one category that could be allocated to field crops but not to specific commodities and another that could be attributed only to general research on crop production. These are therefore "basic" crop research.

The distribution of commodity revenues among subregions of each state is first calculated from county level data in the 1964 census and the distribution of research emphasis is assumed to be the same. That is, if a particular subregion of Iowa accounts for one-third of Iowa's corn production, one-third of Iowa's expenditures on corn research are allocated to that subregion. This procedure is followed in allocating each of the applied categories of expenditure and basic research is prorated according to the average for the specific commodities. These components are then summed to obtain state specific subregion and region aggregates. The next step entails construction of the "borrowable stock" of research available to producers in a given state. If a state (K) contains a subregion part (i), then research expenditures allocated to similar subregions of other states are aggregated. If this subregion part accounts for fraction F_{iK} of all crop revenue within the state, then the total expense for similar subregions is given weight F_{iK} as these numbers are aggregated over the subregions that are part of the state.

Let e_{ij} refer to crop research expenditures in geoclimatic subregion type i of state j. Similar subregion expenditures for state k are

$$e'_{iK} = \sum_{j=K} e_{ij}$$

and the borrowable stock, R', available to state

k is

$$R'_K = \sum_{i=k} F_{i_K} E'_{i_K}$$

An identical procedure is followed for livestock research and for similar regions.

The research index used in estimation is of the form

$$IR_K = \theta (R_K + OR'_K)$$

where R'_K indicates the stock of research in similar regions or subregions outside the state and O, the weight factor, is an index of pervasiveness which is to be estimated. R_K refers to indigenous research expenditures for the state and θ is a congruency index that signals the degree of agreement between the distribution of farm receipts and the allocation of research funds.

Operationally defined,

$$\theta = (1 - 1/2(\sum_i c_i - r_i)^2)\ f + (1 - F) \qquad (3)$$

where c_i refers to the fraction of crop (livestock) revenue obtained from the i^{th} commodity, r_i is the fraction of applied crop (livestock) research in the state allocated to that commodity, and f is the share of applied in total research. This congruency index is unity if the revenue and research expenditure distribution are identical and falls to the share of basic in total research if all applied research is devoted to commodities not produced within the state.

This index ranged between .99 in Illinois and .25 in Washington for crop research and, for livestock reached a low of .77 in New York and a high of .99 in New Jersey. The unweighted mean for the 48 coterminous U.S. states is .57 for crop research and .93 for livestock.

Notice that research expenditures are not deflated by the number of farms. The problem of identifying units for measuring knowledge is very real and is not addressed here except with respect to geographic pervasiveness. There is a real sense in which knowledge is scale free because as one user acquires information, the stock available to others is not diminished. In this sense, it is not reasonable to deflate by number of users. On the other hand, dissemination of the research product may be easier if the number of potential users is small and deflation by number of farms at least captures some elements of this effect.

Another dimension to the measurement problem lies in the issue of pervasiveness across researchable problems. Suppose, for example, that X research dollars devoted to any commodity increases output of that commodity (holding inputs constant) by precisely a_i percent and that output of other commodities is unaffected. The proportionate increase in product revenue for producers of many inputs would be $\sum_i a_i c_i X_i$ denotes research on the i^{th} commodity c_i is the revenue share and a_i is the commodity-specific research responsiveness. If a_i were constant the "appropriate" index of research activity would be the commodity average research expenditure. On the other hand, if research were fully pervasive, the total expenditure on all commodities and not the average would be the correct measure.

Our procedure for spatial pervasiveness is not to deflate for number of users but to limit patterns to geoclimatic regions or subregions. The extent of "borrowing" remains an open question to be estimated in estimates of O, the pervasiveness parameter defined in equation 3. For pervasiveness among commodities, we have assumed simply that basic research is fully pervasive among crop or livestock commodities but not between them. For applied research we have taken an intermediate position. With zero pervasiveness and uniform impact the appropriate index is $\sum_i c_i r_i$ with $r_i x = x_i$, x_i being the commodity specific expenditure, and x the total among commodities. Our congruency index is

$$\phi = 1 - \frac{1}{2} \sum_i (c_i - r_i)^2 \qquad (3.a)$$

$$= \sum c_i r_i + (1 - \frac{1}{2}\sum c_i^2 - \frac{1}{2}\sum S_i^2) \qquad (3.b)$$

The first term of equation (3.b) is the zero pervasiveness index and the second term permits an addition for pervasiveness. Notice that the second term increases as the number of commodities increases and as the distribution of research funds and revenue among commodities becomes less varied--as opportunities for commodity pervasiveness increases. These indexes are arbitrary but they stand as a clear alternative to no deflation at all (Latimer and Latimer and Paarlberg) or deflation by number of farms (Griliches, 1964).

With this specification of research variables, the aggregate production function is estimated subject to the constraint that labor is efficiently allocated between crop and livestock production. The environmental efficiency-farm size relations are assumed to be Cobb-Douglas relationships of the form

$$A_s f_1(E_1) = A_i (IR_c)^{a_o}$$

and

$$B_s f_2(E_2) = B_i (IR)^{b_o}$$

where A_i and B_i are neutral indexes that shift with economic class of farm and IR_c and IR are the respective crop and livestock research indexes. These are implemented empirically using dummy variables for the USDA specification of economic class of commercial farm. The research indexes, $IR = \phi (R + OR')$, are estimated by iterating over various values of the spacial pervasiveness index, 0, to minimize the residual quadratic given in equation (2).

The results offer support for the hypotheses that agricultural output is affected both by research within the state in which output is observed and by research in similar subregions (or regions) of other states. They are summarized in Table 3. Interestingly, the estimates of pervasiveness in crop research are not affected by specification of pervasiveness in livestock research and estimates for livestock pervasiveness are independent of the crop specification. Because of this apparent independence, the estimates reported here for pervasiveness parameters of each equation correspond to the related parameter being held constant at the value estimated by this maximum likelihood procedure.

For crop research, when the borrowable stock is defined for regions, no evidence of pervasiveness is found. Statistical results for state-specific research are consistently superior to specifications in which some fraction of similar region research is added. On the other hand, when pervasiveness is restricted to subregions evidence of pervasiveness emerges. These results are summarized in Table 3. Using the similar subregion specification for crop research, the production elasticity estimate, its "statistical significance" and the likelihood of the sample all rise as the pervasiveness index is increased. We consider this strong evidence that (1) crop production is increased by increased research activity and (2) there is significant spillover between similar geoclimatic subregions of the United States.

The evidence for livestock research is less convincing. Notice first that when the research index is restricted to within state expenditures there is no evidence of a significant positive effect. As horizons broaden to similar subregions, the point estimate of the production elasticity changes from negative to positive but the variance of the estimated equation increases. When pervasiveness is expanded to the regional level, the estimates improve. In particular, when 90 to 100% of the expenditures in similar regions is added to expenditures within the state, the effect of livestock appears positive and significant. Evidently, if a story of the impact of livestock oriented research is to be told, the telling is with reference to a very broad geographic base.

Appendix 2

This appendix presents a simple partial equilibrium model which can be used to evaluate the effects of agricultural research on the functional distribution of agricultural incomes. Since the consequences of agricultural research are not unique, agricultural research does not directly enter the model. Its effects on agricultural incomes are traced through its likely consequences such as to technical change, to shifts in the supply of factors of production and to changes in the demand for agricultural output, which in turn determine the functional distribution of income. The key element behind the model is a system of factor supply and output demand equations derived from cost and profit functions. This system is closed by simultaneously considering corresponding factor demand and output supply equations that depend on own factor and output prices and on own exogenous factor supply and output demand shifters. This closed model determines equilibrium factor prices and quantities as well as equilibrium output and its price.

In this appendix, we first consider the case where there are three factors of production, land (Z), labor (L) and capital (K), where one factor, Z, is in fixed supply. We assume that the underlying production function is homogenous of degree one and that no inferior factors of production exist, i.e., no factor input is reduced when the scale of output is increased. These assumptions are not too restrictive since they can be relaxed. In such case, the income distribution effects of exogenous changes in factor supplies and output demand, and of neutral or biased technical change can be determined given empirical estimates of all the relevant parameters of the model. However, we confine ourselves to the model with the above mentioned assumptions in order to know the distributional consequences of relevant parameter shifts in an ex ante framework.

Consider a profit function that describes a production system with two variable factors of production, L and K (with prices W and R, respectively), a fixed factor, Z^* (with price S); one output, Y (with price P); and a technology shifter related to time t:

$$(1)\quad \Pi = \Pi(W,R,P,Z^*,t)$$

By Shepperd's Lemma, we can obtain the following factor demand and output supply equations

$$(2)\quad -L = \Pi_W(W,R,P,Z^*,t) \lesseqgtr 0$$

$$-K = \Pi_R(W,R,P,Z^*,t) \lesseqgtr 0$$

$$Y = \Pi_P(W,R,P,Z^*,t) \gtreqless 0$$

Table 3. Estimates of Effects of Crop and Livestock Research on Farm Production with Alternative Assumptions of Special Pervasiveness.

	Estimated Production Elasticity for Research Index	Coefficient Estimated Divided by Standard Error[a]	Variance of the Estimated Equation[a]
A. Crop Research			
State Expenditures Only	.0138	8.93	.2189
State + .25 Similar Subregions	.0211	14.18	.2182
State + .50 Similar Subregions	.0244	16.60	.2179
State + .75 Similar Subregions	.0280	19.21	.2174
State + .90 Similar Subregions	.0290	19.96	.2172
State +1.00 Similar Subregions	.0299	20.66	.2171
B. Livestock Research			
State Expenditures Only	-.0367	-1.77	.2219
State + .25 Similar Subregions	-.0269	-1.09	.2257
State + .50 Similar Subregions	-.0115	-0.45	.2277
State +1.00 Similar Subregions	.0002	0.08	.2281
State + .50 Similar Subregions	.0445	1.23	.2248
State + .75 Similar Subregions	.0675	1.81	.2207
State + .90 Similar Subregions	.0756	2.03	.2206
State +1.00 Similar Subregions	.0821	2.20	.2171

[a]These are asymptotic normal statistics as described in the text.

where Π_i is the partial derivative of Π with respect to price i.

Differentiating these equations totally and expressing all variables in terms of time rates of change, we obtain

$$(3)\quad L' = \beta_{LL}W' + \beta_{LK}R' + \beta_{LY}P' + \beta_{LZ}Z^* + E_L'$$
$$K' = \beta_{KL}W' + \beta_{KK}R' + \beta_{KY}P' + \beta_{KZ}Z^* + E_K'$$
$$Y' = \beta_{YL}W' + \beta_{YK}R' + \beta_{YY}P' + \beta_{YZ}Z^* + E_Y'$$

where $\beta_{ij} = -\Pi_{ij}\frac{W_j}{X_i}$ = elasticities of factor demand with respect to factor prices

$\beta_{iY} = -\Pi_{iY}\frac{P}{X_i}$ = elasticities of factor demand with respect to output prices

$\beta_{Yj} = -\Pi_{Yj}\frac{W_j}{Y}$ = output supply elasticities with respect to input prices

$\beta_{YY} = \Pi_{YY}\frac{P_i}{Y}$ = output supply elasticities with respect to output prices

$E_i' = \frac{\partial X_i}{\partial t}\frac{1}{X_i}$, $E_Y' = \frac{\partial Y}{\partial t}\frac{1}{Y}$ } = factor demand and output supply shifts due to technical changes given output and factor prices

β_{iZ} and β_{YZ} = factor demand and output supply shifts due to a shift in supply of the fixed factor.

Equation system (3) is closed by adding the following factor supply and output demand equations in terms of time rates of change

$$(4)\quad L' = \varepsilon_L W' + L^*$$
$$K' = \varepsilon_K R' + K^*$$
$$Y' = \alpha P' + D^*$$

where $\varepsilon_i (\gtrless 0)$ is a factor supply elasticity, $\alpha (\lessgtr 0)$ is the output demand elasticity and L*, K* and D* are exogenously given shifters.

Combining (3) and (4), we obtain in matrix notion the following

(5)

$$\begin{bmatrix} \beta_{LL}-\varepsilon_L & \beta_{LK} & \beta_{LY} \\ \beta_{KL} & \beta_{KK}-\varepsilon_K & \beta_{KY} \\ \beta_{YL} & \beta_{YK} & \beta_{YY}-\alpha \end{bmatrix} \begin{bmatrix} W' \\ R' \\ P' \end{bmatrix} = \begin{bmatrix} L^* & -Z^* & -E_L' \\ K^* & -Z^* & -E_K' \\ D^* & -Z^* & -E_Y' \end{bmatrix}$$

the solution to which is

(6)

$$\begin{bmatrix} W' \\ R' \\ P' \end{bmatrix} = |G|^{-1} \begin{bmatrix} G_{LL} & G_{LK} & G_{LY} \\ G_{KL} & G_{KK} & G_{KY} \\ G_{YL} & G_{YK} & G_{YY} \end{bmatrix} \begin{bmatrix} L^* - Z^* - E_L' \\ K^* - Z^* - E_K' \\ D^* - Z^* - E_Y' \end{bmatrix}$$

By tracing the sign of the β matrix back to the matrix of second order derivatives of the profit function (which is non-negative definite), we can establish that

(7) $|G|^{-1} \geq 0$

From our assumption of non-inferiority of factors, we know that

(8) $\beta_{LY} \geq 0,\ \beta_{KY} \geq 0,\ \beta_{YL} \leq 0,\ \beta_{YK} \leq 0$

Finally, from the convexity property of profit functions, we also know that

(9) $\beta_{LL} - \varepsilon_L \leq 0,\ \beta_{KK} - \varepsilon_K \leq 0,\ \beta_{YY} - \alpha \geq 0$

These conditions (8) and (9) allow us to establish that 5/

(10) $G_{LL} \leq 0,\ G_{KK} \leq 0,\ G_{YY} \geq 0$

$G_{LK} \gtrless 0,\ G_{KL} \gtrless 0$

$G_{LY} \geq 0,\ G_{KY} \geq 0$

$G_{YL} \leq 0,\ G_{YK} \leq 0$

Equation system (3) derived from a profit function can be uniquely related to that derived from a cost function which corresponds to a cost minimization problem with two variable inputs, one variable output, one fixed production factor, and an underlying linear homogeneous production function. In this instance, the E' variables in (3) can be interpreted as follows:

(11) $E_i' = \beta_{iY} T' + A_Z' - A_i'$

$E_Y' = \beta_{YY} T' + A_Z'$

where T' refers to the overall rate of technical change and the A_i' ($= \frac{\partial X_i}{\partial t} \frac{1}{x_i}$ given factor prices and output levels) are the factoral rates of technical change.

Rewriting equation system (6), we have

(12)

$$\begin{bmatrix} W' \\ R' \\ P' \end{bmatrix} = |G|^{-1} \begin{bmatrix} G_{LL} & G_{LK} & G_{LY} \\ G_{KL} & G_{KK} & G_{KY} \\ G_{YL} & G_{YK} & G_{YY} \end{bmatrix} \begin{bmatrix} L^* - Z^* - \beta_{LY} T' - A_Z' + A_L' \\ K^* - Z^* - \beta_{KK} T' - A_Z' + A_K' \\ D^* - Z^* - \beta_{YY} T' - A_Z' \end{bmatrix}$$

which allows us to establish the following:

(13) $\frac{\partial W'}{\partial L^*} \leq 0,\ \frac{\partial R'}{\partial K^*} \leq 0$

(14) $\frac{\partial P'}{\partial L^*} \leq 0,\ \frac{\partial P'}{\partial K^*} \leq 0$

(15) $\frac{\partial \left(\frac{W}{P}\right)'}{\partial L^*} \leq 0,\ \frac{\partial \left(\frac{R}{P}\right)'}{\partial L^*} \leq 0$

(16) $\frac{\partial \left(\frac{W}{R}\right)'}{\partial L^*} \leq 0\ \frac{\partial \left(\frac{R}{W}\right)'}{\partial K^*} \leq 0$

(17) $\frac{\partial W'}{\partial Z^*} \gtrless 0\ \frac{\partial R'}{\partial Z^*} \gtrless 0$

(18) $\frac{\partial \left(\frac{W}{P}\right)'}{\partial Z^*} \gtrless 0\ \frac{\partial \left(\frac{R}{P}\right)'}{\partial Z^*} \gtrless 0$

(19) $\frac{\partial W'}{\partial K^*} \gtrless 0\ \frac{\partial R'}{\partial L^*} \gtrless 0$

(20) $\frac{\partial \left(\frac{W}{P}\right)'}{\partial K^*} \gtrless 0\ \frac{\partial \left(\frac{R}{P}\right)'}{\partial L^*} \gtrless 0$

(21) $\frac{\partial W'}{\partial D^*} \geq 0\ \frac{\partial R'}{\partial D^*} \geq 0$

(22) $\frac{\partial P'}{\partial D^*} \geq 0$

(23) $\frac{\partial \left(\frac{W}{P}\right)'}{\partial D^*} \gtrless 0\ \frac{\partial \left(\frac{R}{P}\right)'}{\partial D^*} \gtrless 0$

(24) $\frac{\partial W'}{\partial T'} = -(\alpha + 1) \frac{\partial W'}{\partial D^*},\ \frac{\partial R'}{\partial T'} = -(\alpha + 1) \frac{\partial R'}{\partial D^*}$

(25) $\frac{\partial P'}{\partial T'} \leq 0$

(26) $\frac{\partial\left(\frac{W}{P}\right)'}{\partial T'} \gtrless 0, \quad \frac{\partial\left(\frac{R}{P}\right)'}{\partial T'} \gtrless 0$

Consider now what happens when technical change that is labor saving occurs at the expense of capital (an LK bias as opposed to a KL bias) assuming that the rate of technical change remains constant, i.e., $dT' = s_L dA_L' + s_K dA_K' + s_Z kA_Z' = 0$ where s_i refers to the value share in output of factor i. In this case, $dA_K' = -\frac{s_L}{s_K} dA_L'$ and $A_K' = -\frac{s_L}{s_K} A_Z'$.

Employing this last relation in (12), we can establish that

(27) $\frac{\partial W'}{\partial A_L'}\Big|_{\text{LK bias}} \leq 0, \quad \frac{\partial W'}{\partial A_K'}\Big|_{\text{KL bias}} \geq 0$

(28) $\frac{\partial P'}{\partial A_L'}\Big|_{\text{LK bias}} \gtrless 0$

(29) $\frac{\partial\left(\frac{R}{P}\right)'}{\partial A_L'}\Big|_{\text{LK bias}} \gtrless 0$

When there are more than one region, the distributional effects of agricultural extension become more varied. In the simplest case where there are only two regions, two factors of production, L and Z, where Z is fixed, and one output Y, the time rates of change in regional labor wages and output prices, W_r' and P_r', would depend on whether labor and output are freely mobile across regions.

Consider first the case where labor is mobile and output is freely traded across regions, i.e., $W_1' = W_2' = W'$ and $P_1' = P_2' = P'$ where the subscripts refer to the regions. Closely following the derivations used earlier for the one region case, we obtain an equation system analogous to (6), i.e.,

(30)
$$\begin{bmatrix} W' \\ P' \end{bmatrix} = \begin{bmatrix} \bar{\beta}_{YY} - \alpha & -\bar{\beta}_{LY} \\ -\bar{\beta}_{YL} & \bar{\beta}_{LL} - \varepsilon_L \end{bmatrix} \begin{bmatrix} L^* - \lambda_1 Z_1^* - \lambda_2 Z_2^* - \lambda_1 E_{L1}' - \lambda_2 E_{L2}' \\ D^* - \nu_1 Z_1^* - \nu_2 Z_2^* - X_1 E_{Y1}' - \lambda_2 E_{Y2}' \end{bmatrix}$$

where $\bar{\beta}_{LL} = \lambda_1 \beta_{LL1} + \lambda_2 \beta_{LL2} \leq 0$

$\bar{\beta}_{YL} = \nu_1 \beta_{YL1} + \nu_2 \beta_{YL2} \leq 0$

$\bar{\beta}_{LY} = \nu_1 \beta_{LY1} + \nu_2 \beta_{LY2} \geq 0$

$\bar{\beta}_{YY} = \nu_1 \beta_{YY1} + \nu_2 \beta_{YY2} \geq 0$

$\lambda_r = \frac{L_r}{L}, \quad r = 1, 2$

$\nu_r = Y_r/Y, \quad r = 1, 2$

and the subscripts 1 and 2 refer to the regions.

From (30) we cam gather that

(31) $\frac{\partial W'}{\partial L^*} \leq 0$

(32) $\frac{\partial P'}{\partial L^*} \leq 0$

(33) $\frac{\partial\left(\frac{W}{P}\right)'}{\partial L^*} \leq 0$

(34) $\frac{\partial W'}{\partial Z_r^*} \lessgtr 0$

(35) $\frac{\partial P'}{\partial Z_r^*} \leq 0$

(36) $\frac{\partial\left(\frac{W}{P}\right)'}{\partial Z^*} \geq 0$

(37) $\frac{\partial W'}{\partial D^*} \geq 0$

(38) $\frac{\partial P'}{\partial D^*} \geq 0$

(39) $\frac{\partial\left(\frac{W}{P}\right)'}{\partial D^*} \leq 0$

When labor is immobile between regions though output is not, we can construct an equation similar to (30), i.e.,

(40)
$$\begin{bmatrix} W_1' \\ W_2' \\ P' \end{bmatrix} = |G|^{-1} \begin{bmatrix} G_{11} & G_{12} & G_{1Y} \\ G_{21} & G_{22} & G_{2Y} \\ G_{Y1} & G_{Y2} & G_{YY} \end{bmatrix} \begin{bmatrix} L_1^* - Z_1^* - E_{L1}' \\ L_2^* - Z_2^* - E_{L2}' \\ D^* - \nu_1 Z_1^* - \nu_2 Z_2^* - \nu_1 E_{Y2}' - \nu_2 E_{Y2}' \end{bmatrix}$$

where $G_{11} \leq 0, \; G_{22} \leq 0, \; G_{YY} \geq 0$

$G_{12} \geq 0, \; G_{1Y} \geq 0$

$G_{21} \leq 0,\ G_{2Y} \geq 0$

$G_{Y1} \leq 0,\ G_{Y2} \leq 0$

In this immobile labor case, we can obtain the following effects:

(41) $\frac{\partial W_1'}{\partial L_1^*} \leq 0,\ \frac{\partial W_1'}{\partial L_2^*} \leq 0$

(42) $\frac{\partial P'}{\partial L_1^*} \leq 0$

(43) $\frac{\partial\left(\frac{W_1}{P}\right)'}{\partial L_1^*} \leq 0,\ \frac{\partial\left(\frac{W_1}{P}\right)'}{L_2^*} \geq 0$

(44) $\frac{\partial W_1'}{\partial Z_1^*} \gtreqless 0,\ \frac{\partial W_1'}{\partial Z_2^*} \leq 0$

(45) $\frac{\partial P'}{\partial Z_1^*} \leq 0$

(46) $\frac{\partial\left(\frac{W_1}{W_2}\right)'}{L_1^*} \geq 0$ $\frac{\partial\left(\frac{W_1}{P}\right)'}{\partial Z_2^*} \gtrless 0$ (47) $\frac{\partial\left(\frac{W_1}{W_2}\right)'}{\partial L_1^*} \leq 0$

(48) $\frac{\partial W_1'}{\partial D^*} \geq 0,\ \frac{\partial W_2'}{\partial D^*} \geq 0$

(49) $\frac{\partial P'}{\partial D^*} \geq 0$

(50) $\frac{\partial\left(\frac{W_1}{P}\right)'}{\partial D^*} \leq 0,\ \frac{\partial\left(\frac{W_2}{P}\right)'}{\partial D^*} \leq 0$

(51) $\frac{\partial\left(\frac{W_1}{W_2}\right)'}{\partial L_2^*} \geq 0$

(52) $\frac{\partial P'}{\partial T_1'} \leq 0$

(53) $\frac{\partial W_1'}{\partial T_1'} \gtreqless 0,\ \frac{\partial W_1'}{\partial T_2'} \leq 0$

(54) $\frac{\partial\left(\frac{W_1}{P}\right)'}{\partial T_1'} \geq 0,\ \frac{\partial\left(\frac{W_1}{P}\right)'}{\partial T_2'} \leq 0$

Footnotes

1/ For the conditions which must be imposed on the transformation function, see Diewert, 1978.

2/ See Evenson (1975), Evenson and Kislev (1974), Binswanger and Evenson (1976), and Evenson, Herdt, et. al. (1976) for a discussion of this literature.

3/ See Freeman (1973), Hardwick and Wood (1972), Laing Fisher (1973), and Finlay and Wilkinson (1963).

4/ They include: barley, corn and sorghum, cotton, flax, forestry and forest products, fruits, hay, oats, peanuts, potatoes, rice, soybeans, sugarbeets and sugarcane, tobacco, vegetables, and wheat.

5/ Profit functions are homogenous of degree one in input and output prices. We also use this property to establish the relations in (10).

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