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Evaluation of Agricultural Research

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EVALUATION OF AGRICULTURAL RESEARCH

Proceedings of a Symposium Sponsored by NC-148

(Analysis of Returns to Agricultural and Related Research in the North Central Region)

Minneapolis, May 12-13, 1980

Agricultural Experiment Station

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PREFACE

This publication reports the proceedings of a symposium held in Minneapolis, May 12-13, 1980. The symposium was organized by the Technical Committee of North Central Regional Project NC-148, Analysis of Returns to Agricultural and Related Research in the North Central Region. Since its inception in 1978, this Regional Project has provided a forum for discussing issues of research evaluation and productivity with participation open to individuals from other regions of the U.S.

The subject matter of Regional Project NC-148 is a continuation of earlier interests which resulted in a symposium held in Minneapolis on February 23-25, 1969. The proceedings of the 1969 symposium were reported in Resource Allocation in Agricultural Research, edited by Walter L. Fishel and published by the University of Minnesota Press in 1971. A subsequent symposium, held at Airlie House in January 1975, had the broader international arena of agricultural research and research systems as its focus. The proceedings of the Airlie House symposium were reported in Resource Allocation and Productivity in National and International Agricultural Research, edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan and published by the University of Minnesota Press in 1976. A third major symposium was held at the University of Idaho in May, 1978. The proceedings of this symposium, which emphasized appraisal of productivity of extension as well as research, was published in March 1980 in Research and Extension Productivity in Agriculture, edited by A. A. Araji and published by the Idaho State Agricultural Experiment Station.

Issues concerned with the evaluation of agricultural research and agricultural productivity have also been discussed in numerous sections of regional, national and international conferences. For example, in 1978 the topic of evaluation of agricultural research and extension was discussed at the summer meetings of the American Agricultural Economics Association in Blacksburg, Virginia. The February 1978 meeting of the AAAS held in Washington, D.C. addressed the topic of agricultural research productivity as did a conference sponsored by the Ford Foundation in New York City in February 1979 and the Conference of the International Association of Agricultural Economists held in Banff, Alberta in September 1979. In addition, a number of papers have been published dealing with this and related topics in the American Journal of Agricultural Economics and in other publications. Finally, since 1979, discussions and research on agricultural research evaluation have been conducted under the auspices of IR-6, an interregional project on agricultural research planning, evaluation and analysis. Several papers presented at this symposium were developed under the auspices of IR-6. Thus, this proceedings reports work which drew on a decade or more of discussion of research productivity in agriculture.

The purposes of the 1980 Minneapolis symposium were to once again address the need for evaluation of agricultural research, to assess the research underway on this topic and to project additional needs in terms of methodology and subject matter coverage. Methodology particularly was an avowed focus of the conference, although the planning committee encouraged the reporting of empirical findings as well. Because some of the authors report research in progress, several of the papers are of a preliminary nature.

The proceedings which follow are organized under five general headings: (1) a challenge to the sumposium in terms of requirements for evaluation information, (2) a comprehensive review of past methodology, (3) issues related to the productivity and transferability of agricultural research, (4) issues and analyses pertaining to research management and funding, and (5) expansion of evaluative methodologies and needed applications. It was the intent of the symposium both to report work on research evaluation and to subject it to constructive evaluation in terms of research needs and available methodologies. Thus, a number of the papers are cast in the context of methodology evaluation. The final paper by Rausser, et al, in fact presents a critical review of much of the previous work on research evaluation and suggests moving toward a sequential process of evaluation which requires evaluative input from the time of determining which research topics are to be addressed, who the research will impact and who should provide the research funding.

Minnesota Agricultural Experiment Station in making possible both the conference and this proceedings issue. We also appreciate the contribution of all who participated in the symposium and the cooperation of authors in preparing their papers for this proceedings. Special thanks are due to Sam Brungardt for his editing and publication management services, to Nancy VanHemert for her efforts in organizing and helping to manage the manuscript typing project and to Cindy Smith and Nan Bruns for typing and proofing the many manuscripts.

The Symposium Planning and Editorial Committee
George W. Norton
Walter L. Fishel
Arnold A. Paulsen
W. Burt Sundquist

This volume is dedicated to

DONALD R. KALDOR

who was a member of NC-148 from its beginning to his death on October 9, 1978.

Dr. Kaldor was active professionally from 1966 until his death in developing procedures for evaluating the future impacts of alternative agricultural research investments. Don was very interested in *ex ante* evaluation of research in spite of its difficulty because he believed such evaluation was critical in formulating more valuable long range agricultural research programs.

In 1966 Don Kaldor was asked by the Iowa Agricultural Experiment Station to advise on research program planning. In 1968 Iowa State undertook a comprehensive long range agricultural research program planning effort using procedures designed by Don Kaldor. This research evaluation effort involved 20 interdisciplinary panels of scientists who proposed and ranked research alternatives called "information packages." The cost of each research alternative was estimated and the set ranked by resource efficiency in contributing to Iowa and U.S. economic growth.

During the 6 years he worked as a consultant and researcher with USDA's Cooperative State Research Service, Don Kaldor assisted with several state experiment station program planning efforts and participated in regional and national research program planning efforts. Don Kaldor brought a public policy framework to agricultural research program evaluation and planning. His professional involvement spanned 12 years from the first comprehensive inventory and classification of agricultural research in the 1966 Long Range Study to the 1977 farm bill which created the Joint Council on Food and Agricultural Sciences.

Part of the range of Don Kaldor's interests and contributions to *ex ante* agricultural research evaluation is evidenced by three papers in this volume by three of his students--one by Joe Murphy on constructing an index of the cost of doing agricultural research, another by Janelle Ramsdale describing the individual decisionmaking of agricultural scientists and a third by John Strauss on goal structure for agricultural research program planning.

EXPANSION OF METHODOLOGIES AND APPLICATIONS

CHANGES IN THE NEED FOR RESEARCH AND EXTENSION EVALUATION INFORMATION

Walter L. Fishel*

There is little question that we are facing an increasing number of requests for more and more information on the payoff to public outlays for research. At every turn, there is another policy group, budget makers, symposium, or "futures" of world food study wanting more information on research and extension (R&E) cost-benefits or rates-of-return than we are presently capable of providing. This certainly indicates that something is happening in this environment in which R&E evaluation is carried out. We must assume that it is not simply idle curiosity that is causing this apparent awakening to something to which many have been devoting their attention for years.

It would seem useful to briefly consider the overall environment within which R&E evaluation is to be made and used. To do this, I would like to consider three topics: the trends and factors that are indicating a need for more and better R&E evaluation information, the roles and requirements of R&E evaluation information, and some thoughts on the challenge to those who will continue to develop R&E evaluation information.

An Assessment of the R&E Evaluation Environment

To meet these increasing requirements for R&E evaluation information, we need to spend some time in assessing what these information needs are, what it is in the R&E evaluation environment that is creating that need and, in fact, what the environment is. Else, we may continue to generate figures about payoff in greater and greater quantities and only assume that this is the information that those who want the information actually need. It is not just the quantity of R&E evaluation information but the particular nature and content that is important.

We have probably assumed the R&E evaluation environment to be a relatively homogeneous entity in which needs for R&E evaluation information are quite singular in characteristic. This may simply reflect our preoccupation to date with R&E evaluation methodology. Unfortunately, the R&E evaluation environment is a most complex array of interlocking factors which precludes such simplistic assumptions.

In general, the R&E evaluation environment is the composite agricultural and food industry, the policymaking and resource allocation bodies and processes, the totality of the public and private agricultural and food research enterprise, and the R&E evaluation community itself, including its performers, organizations, disciplines, models, methodology, data and more. This is an austere array of areas that should influence what we decide to do in R&E evaluation efforts and how we do it. It is my contention that it would benefit us to consider these areas of the environment for the more significant changes that are occurring in this complex environment and the effect these may have on what we should be giving primary attention to in the development of R&E evaluation information.

Three broad areas of change in our environment are having substantial influence on the need for and characteristics of R&E evaluation information. These are (1) trends in agricultural production and related areas, (2) fundamental changes in the socioeconomic environment, and (3) changes in the agricultural research community itself.

Trends in Agricultural Production

The concerns about trends in agricultural production are well known as are their conjectured impacts. I need not dwell on these. The general population suddenly became aware of a "limits-to-growth" possibility during the food crises of the early 1970s. However, even the less emotional of concerned individuals point to the drop in the rate of increase of agricultural production from 24% during the 1950s to 11% in the 1960s {1}, a decline which continued during the 1970s, as indicating some need for concern about the potential of agriculture to meet future food requirements.

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least of these are the changes in social goals which emphasize environmental quality and food safety and health factors, both of which impact negatively on the quantity of agricultural production. Another explanation involves changing patterns of resource quality, availability and cost--climate and weather patterns becoming less favorable, resources becoming more costly as supplies dwindle or as international political relationships change, and the continuing high rate of inflation. Other explanations point to a stabilized level of R&E funding that in real terms hasn't increased since the mid-1960s, the research that is done being more costly and the problems investigated being increasingly more complex. Yet, there is real and documented concern that agricultural production is indeed reaching the biological limits of existing knowledge in several areas and that substantial shifts in research emphasis are needed {2,3,4}.

There are obviously many questions to be answered in these trends related to the fundamental issues of "What is it feasible to do?" and "What is it relevant to do?" It is important to know what are the sources of the reduced rate of growth of agricultural production, which of these do we reflect in our goal structure, which in our "pricing" structure, which are indeed limitations to growth and, consequently, which can we do something about...and what?

Trends in Socioeconomic Factors

Two basic types of changes can be mentioned here--those in or impacting on key economic resources (natural resources, factor inputs, energy, climate and weather, inflation, etc.) and those representing changes in societal goals (environmental quality, nutrition and food safety, and many more). These are not independent influences but highly interlocking in how they affect agriculture and the channels through which the effect operates.

The array of economic related factors is substantial. In the area of natural resources, we are experiencing increasing competition from non-agricultural sources for land, and it is seldom over the poorer producing land. Increasingly, marginal or previously nonproductive land (desert) is being brought into production, and we are experiencing an increasing incidence of unstable soil conditions which affects geographical areas other than the source. Climate and weather conditions have moved into a period of extremes where drought, floods, heat, and cold are alternately experienced, whereas our high producing crop varieties were developed during an extended period of favorable conditions. Water availability and quality is increasingly becoming a more important factor in production decisions requirements are paramount considerations as oil prices quadrupled, changing patterns of energy use, requiring new ways of running our agricultural plant to get around deficiencies and high cost, patterning whole farming systems around this one resource, and finding ways to counteract devastation of lands from energy extraction activities (strip mining). Double-digit inflation followed by an expected sustained rate of at least 6-8% has continuing traumatic effects throughout domestic factor and international commodity markets. One could also discuss at some length the economic effects associated with changing size and scale of farm and marketing organizations and affiliated institutional structures.

The story is little different with respect to changing social goals and institutions. The changes that have occurred in the last decade represent an interesting period in our history. We have seen the impetus of social goals change basically from one concerned with "survival" to one concerned with "consumption." The historical concern with growth in GNP has been replaced with verbiage on "zero growth" and a preoccupation with "quality of life" and "equity." The effect of this has been felt in such areas as more stringent regulations on environmental quality, on food labeling and additives, and food safety. It is also reflected in pressures to preserve "proper" balances between personal income and food prices among others, and the impact of many technology changes in agriculture on rural families, farm-to-city migration, availability of opportunities, technologies, and markets for city-employed farmers and for marginal subsistence farm operators and a number of other similar goals.

The foregoing obviously presents a perplexing array of factors to be simultaneously considered by public policymakers and research administrators. They must contend with wholly different patterns of resource emphasis than the traditional ones. Many of these require substantial shifts in emphasis and consequently frequently run head on into established positions and interests. They face very hard questions like how much of the resources should go into production increasing research versus "defensive" types of research--a problem faced by public as well as private research organizations. Certainly the old resource allocation equations have many new variables in them.

Trends in Agricultural Research

The science system as a whole has been involved in a strange paradox in recent years. On the one hand, it has been the object of almost unrequited overconfidence in its capacity its products and to some extent even its motives. One can note the impact of this in several trends in the agricultural research system. A second interesting occurrence specific to agriculture has been the large number of studies of the agricultural research community--15 major studies and conferences at last count {5,6}. Yet another major one is now underway in the Congressional Office of Technology Assessment. This is surely indicative that something out of the ordinary is happening to which we should be responsive in our R&E evaluation efforts.

With respect to the research activity itself, we note that research is increasingly conducted within a "systems" context that is multidisciplinary and multivalued, such as research on crop growth models or pest management systems. There has been a gradual shift away from basic research to applied research to provide faster payoffs. Agricultural research is becoming involved in new areas of research or increasing efforts in areas previously underemphasized by traditional research organizations. These include energy as a separate area of inquiry, new food sources and production methods, human nutrition, economic uses of plant and animal (and human) waste, information as a substitute for depleting capital availability and others.

The organization of agriculture is also undergoing some significant changes. There has been a sudden opening up of what the Mayers referred to as "the island empire" {7} through an increasing emphasis on the roles and responsibility of private sector research as well as greater emphasis on extramural research in federal research programs and on various grants programs. There has been almost a dogged insistence on programmatic-oriented devices that assure a coordinated strategy among all participants in the research process. Congress and the executive have become more involved in determining what research is and is not to be done, aided in no little measure by advisory bodies relatively new to the area of agriculture. Other significant changes in research organizations include the separating out of functional areas like nutrition, energy, and pollution as separate research entities, increases in scale of facilities to support high cost research equipment, and a tendency to specialization of research areas of inquiry reflected in the establishment of centers. Certainly, the rapid growth and capabilities of the international research centers and their capabilities should not be omitted for their impact on R&E evaluation endeavors.

In considering changes in funding of agricultural research, it is the lack of change that is the most disturbing. Through glut or shortage, the USDA's research budget has remained at about 2% of the federal total R&D outlays since the trailed by a wide margin increases in research funding for HHS, NSF, EPA, and NSF, our major competitors. Significantly, funding for "biological" research has declined in the USDA since 1970 while increasing markedly for HHS and somewhat for both NSF and EPA {8}. Further, while the Food and Agricultural Act of 1977 designated substantial new charges to the agricultural R&E community, it provided no additional funding to carry them out.

A most significant trend from the standpoint of evaluation efforts is a widespread pressure throughout the federal and even many state bureaucracies for more accountability in our resource allocation processes. Unfortunately, the trend isn't policy oriented; it is management oriented. Under this influence, great importance is placed on coordination and control mechanisms and documented evidence of past successes are not quite as important as visible indications that we have been "neat" in our research management processes. Certainly, the federal-state-private system fails according to this criterion. The emphasis is not so much on providing cost-benefit figures for research as it is to have well-organized management structures and planning processes to develop the cost-benefit measures.

Finally, there has been a pervasive change in attitudes regarding the appropriateness of funding methods. Historically, we have lived with formula or institutional funding for both state and federal research organizations. Almost overnight, widespread pressures have surfaced to move away from institutional or formula funding to grant , contract, and privately financed research. In part, this reflects the growing uncertainty about the "island empire's" ability to respond fully to national needs; in part, it reflects the interest of non-traditional agricultural research organizations to share in the formula funding "pot." Irregardless, the change in attitude indicates a growing pressure that is shifting research organization, planning, and funding away from a resource orientation more toward a program orientation.

Again, the kinds of trends observed here present a difficult set of variables for policymakers, research planners, and resource allocators in agriculture to cope with. Significantly, the kinds of decisions faced require more information than simply rates-of-return to research for a commodity area. There is a broader array of questions including who performs the research, when, where, and how to fit the pieces into a single research strategy. These are not simple, singular issues to handle.

As a first step in making sense out of the foregoing, it may be noted that there is a rational trend to what is happening at the present time. There is a structure of change that reflects where we are in the evolution of planning and decision philosophies in agriculture. That is, if one looks back in a very general way at the context within which allocation decisions have been viewed, formulated, and analyzed, there seems to emerge several general stages of development. Up to the 1920s and 1930s research and research organization and planning seemed to be largely concerned with "discovery," trying to unravel the basic mysteries of nature. Somewhere around the 1920s we began placing more emphasis on the "control" of nature in terms of production knowhow, improved management of our environment, and more effective flow or distribution of products and commodities. Somewhere up to the end of the decade of the 1950s or early 1960s, the emphasis in selecting research was on "efficiency"--how to get more for less. This period tended to encourage relatively specific research topics locked into a single field or discipline. In the early part of the 1960s, there was a shift in attitude associated with environmental and equity concerns and later associated with the youth revolution that seemed to question the "relevance" of the research being done. Fields of research that were new to agriculture emerged. Later in the decade and extending on into the 1970s we entered the age of "systems" in which it was recognized that "problems" could not be studied independently but that sometimes very complicated interrelationships had to be reflected in our problem definition and analysis. However, research was still largely carried out within the context of traditional areas of investigation. In the latter part of the decade we have almost been propelled into a fourth planning philosophy, that is referred to as the "holistic" perspective, or the age of "comprehensive analysis" as one calls it. This age is characterized by the totality of interrelationships and, equally significant, the tenuousness of solutions. We now concentrate on developing continuing processes for change rather than seeking discrete answers or one-time solutions. I emphasize the fact that at no time have we relinquished any previous stage completely, but rather adopted yet a new one on top of the old.

There are several significant features of this evolution that are relevant to R&E evaluation considerations. First, in the earlier stages, research was predominantly centered about separate, individual investigations and discoveries relating to single disciplines and characterized by the Heidelberg and Vienna schools of philosophy. In later stages, group, team, multidiscipline organizations and approaches to research have become increasingly more important and demanded that was the determining factor in research organization and planning.

A second major factor is that when research organizations and institutions get out of phase with the prevailing stage of research information philosophy, things happen. Usually, there is reorganization of some sort which is nearly always induced from outside the existing organization. What is happening now in the federal-state system is no different than has happened before. What is different is that changes have been coming faster and faster, one heaped on top of another. This does not provide much chance for one to adjust perspectives to a new situation and develop workable relationships with the new situation before another is begun.

The third factor is that the social sector and the science community are beginning to converge with respect to policy and planning structures, information development processes, and, most importantly, in basic "relevance" and "appropriateness" philosophies. Evidence of this has shown up in several areas of our society. However, this does not mean they will or can completely converge. The pluralism/elitism paradox that we face in our increasingly more complex social and technical environment will assure that we continue to ebb and flow between what it is feasible to do and what it is relevant to do. Conflict between the two will continue because we cannot have consensus of goals nor perfect information.

Information relative to research becomes a key issue in all this. The goals of our pluralistic society and the technology of our elitist science community are no longer as independent as they once were. Increasingly, policy and resource allocation decisions are being made within "frameworks" that implicitly relate means to ends, that indicate negative by-products, that reflect strategies for most effectively achieving ends over time and by the appropriate performers. The primary implication to us is the need for a perspective attuned to these conceptual frameworks and the development of information determined by and aimed at the needs of these conceptual frameworks.

The Roles and Characteristics of R&E Evaluation Information

As a general rule, we do tend to view R&E evaluation figures as somewhat homogeneous entities, although variable in quality, which are equally applicable to almost any decision situation. It is true that any rate-of-return or benefit-cost ratio can be an input into almost any decisionmaking situation, but it is not true that they are uniformly applicable. Decision situations are simply too heterogeneous in their cases they are inadequate.

R&E evaluation information used in decision situations varies in several respects, one being the purpose for which it is intended. However, there are several important dimensions to information. I would describe the quality of information as consisting of the dimensions of "identification" (whether or not all relevant factors have been included), "precision" (whether or not the data sources and analytical methods adequately measure the influence of these factors), and "reliability" (whether or not the user of the information generated has confidence in it). These dimensions do vary in relative importance among decision situations. There are other significant dimensions. Two of these, "timeliness" and "cost," relate directly to the three basic dimensions. In most decison situations with which I am acquainted, one or the other or both of the latter become the primary limiting dimension with identification and precision carried to a level consistent with these limitations. R&E evaluation information that is very precise but takes too much time to develop is less useful than timely information that is not very precise at all.

Roles, Characteristics, and Use

With this as a base of discussion, I would like to concentrate on three broad roles of R&E evaluation information--education, policymaking, and resource allocation--and the characteristics or dimensions associated with each.

"Education" may not be the most appropriate term for the first role considered but it does best describe what I consider to be the most relevant function in this role. R&E evaluation information applicable to this role has the primary function of making us more knowledgeable about the R&E environment. It is, in effect, foundation or base knowledge. The information is applicable to everyone who makes policy or allocates resources or studies these areas. The principal sources of this R&E information have been the *ex post* analyses which measure the tracks previous research have left on our economy.

The "policymaking" role for R&E evaluation information is the most difficult one to describe. This may be why we have relied so heavily in the past on information in the education role to satisfy the information needs in this area. First of all, the situation relating to policymaking is inherently conflict oriented; if conflict is not present then one probably isn't dealing with the making of policy. This implies the comparison of people's basic values as well as of facts. Second, R&E evaluation data is never the full range of information involved, societal values and various types of impacts impacts are usually the information areas of primary interest. Hence, the whole process, while logical, is not rational in the context of expert analysis being rational. Other key requirements are that R&E evaluation information must relate to or be imbedded in a specific decisionmaking framework and that it enunciate alternatives, the latter point being inherent in any conflict situation.

There are two key features of information in the role of "resource allocation," timeliness and specificity of information needs. Most allocation decisions are made on relatively short time lines, some on none at all. Once again, education information is particularly important to provide a foundation for timely decisions. However, nearly all allocation decisions require relatively specific information about alternatives; aggregate measures of R&E evaluation are only useful in very general terms and are never completely adequate. Other needs for R&E evaluation information include alternative strategies for getting research done, including program areas, public-private participation and alternative approaches.

How effective has R&E evaluation information been in each of these decision roles? Without some "real time" observations and recording of information use or even an explicit study of use, response to this question must be based on impressions. These are my impressions.

In the role of educating users of R&E evaluation information, we have probably achieved our singular success. The studies to date and the resulting information have been good and they have been useful. However, most recent success has been more applicable to the international research environment, where much of the study has been conducted, than to the domestic. The international environment is certainly easier to study than the domestic. It is at a less developed state than that in the United States and, consequently, is less fraught with significant complexities. How transferable the knowledge we learn from the international studies is to the domestic situation is conjectural. Insofar as I know, no study of this issue has been conducted.

In the role of policymaking, I would submit that R&E evaluation information has had little direct effect. As background or foundation information as in the context above, R&E evaluation information has provided at least a base for consideration of policy, in the sense that it prevents the filtering out of certain alternatives that "experts" might consider to be, rationally, the better options. However, in most of the policymaking situations I have relied on. For whatever reasons, economic returns information is not considered useful or adequate relative to other information.

Much the same is true for resource allocation decisions. R&E evaluation information has not entered directly in the consideration of program or budget development decisions with which I have been associated at the federal or state levels. With the advent of Zero-Based Budgeting, attention has been given to the development of R&E evaluation information...but after the allocation decisions have already been made. The decisions made by OMB relative to the department's budget submission does not appear to reflect the extensive rates-of-return information developed for them under the auspices of ESCOP. Neither did those of the House Agricultural Committee.

R&E Evaluation Information Requirements

As the characteristics of the roles for R&E evaluation information vary, so also do the requirements for their development. For the educational role we obviously need more of the same studies that have been produced since the mid 1960s, as long as new information is being produced. Herein lies the challenge. The same type of study approaches that were used to analyze the United States system, once the major methods were applied, were generally transferred to application in the international environment. Further significant gains in knowledge about the United States research environment have been relatively limited. New methodology, variables, or data are going to have to be forthcoming to provide the continuing gains in understanding of this complex R&E environment. We do need some innovative efforts.

Requirements for the policymaking role are more substantial. To make my point here, I refer to a framework enunciated by Wright {9} in discussing the informational structure of policymaking. He points out that there are three components to policymaking, namely (1) the policymaking decision itself, (2) "intermediate" knowledge, and (3) the contribution of expert knowledge. The main point is that experts make contributions to policymaking activities that are meaningful within their conceptualization of the policymaking situation. In most cases, this usually consists of a partial analysis of the total decision situation. Someone else must then further analyze the contributions of experts, by means of a more complete analytical framework, to produce what Wright calls intermediate knowledge. It is on the basis of this intermediate knowledge and not that of the experts directly that policymakers base their decisions. If R&E evaluation experts want to or expect to have impact on edge framework more effectively, even if only a partial analysis is intended. Else, two things are apt to happen--the "translation" or interpretation of our expert knowledge is made by someone who is less competent to make such an interpretation, or the information is simply considered interesting, possibly impressive, but not all that relevant.

The needs for R&E evaluation information in the resource allocation role have even more specific needs for detail. Again, the principal features of this role are that it is almost a unique selection among alternatives, in a relatively short timeframe, and probably never to be repeated again in exactly the same form. Hence, the role requires an information orientation, not an analytical one, as the primary driving force for identifying relevant variables, selecting appropriate analytical methodology, acceptance of data quality, etc. That is, one must start with the decision and work backwards. Traditionally, this perspective has required someone other than the discipline oriented expert. A second requirement is that the whole effort be future oriented, how ever much the analysis is based on past studies and data. The R&E evaluation effort is not inherently to predict but to help anticipate based on the best information available. Finally, the R&E evaluation information effort must be scaled to time and cost requirements that are appropriate to the decision being made; identification, precision, and factors that would contribute to statistical reliability are nearly residual attributes to these primary concerns.

"Delivery System" Requirements

An important area of consideration related to R&E evaluation information is the nature of the existing "delivery systems," that is, the linkages between the R&E evaluation information suppliers and those who need the information. The adequacy of this linkage is particularly important since it determines how well requirements in information characteristics are communicated from users to suppliers.

One must conclude that these linkages are not currently entirely adequate to provide effective communication from users to suppliers about the specific nature of information needed, from suppliers to users about what information is available, what it means and what it implies, or to provide an adequate environment within which potential users of R&E evaluation information can become more knowledgeable and more adept in its use.

Linkages for educational purposes may be considered generally adequate with one exception.

the information provided and to "educate" them in its use and relevance as we educate our students in the use of economic principles and data. This may be the most significant fault of all. We inform but we do not change their decisionmaking behavior.

Beyond this, both for policy and resource allocation use, linkages between suppliers and users of R&E evaluation information are nonexistent, loose, or at best, ad hoc. Part of this stems from the fact that policy issues are not generally raised by policymakers but gradually evolve in public rhetoric and become manifest in studies designed and conducted by organizational units disassociated with the policymakers as such. There are exceptions to this but they are relatively few. The important point is that during design phases, there are few established linkages between performers and policymakers to obtain interactions from intended users with respect to users' interests in the specific content of the policy being studied, specification of issues, or the appropriate composition of "shadow prices."

Within the Department of Agriculture and the state agricultural experiment stations, with which I am most familiar, linkages generally are no more than a charge to a study group to go out and do a study without actual involvement at any subsequent point on the part of the policymakers. Most policy-oriented R&E evaluation studies are conceived and conducted within the ESCS or departments of agricultural economics. Much the same is true in the executive, where OMB and now OSTP are delegated to conduct special policy studies. The OSTP probably comes the closest to providing performer-policymaker linkages mainly through the composition of the study groups. One can see a glimmer of hope in the organization of SEA in which an Evaluation and Impact Analysis Staff works closely with administration of that organization. This coupled with the national and regional planning and priority setting groups dictated by Title XIV provides the basic mechanism for this linkage of which I am concerned. The closer the IR-6 Research Committee can associate itself with these planning groups in an operational sense, the more effective this linkage will work. We certainly can hope.

Some Thoughts On the Future of Research Evaluation

The foregoing only touches on the range of factors that shape the policy and resource allocation decisions that are being made today and which indicate the type of R&E evaluation information that is needed. But, there is a challenge to us in the foregoing. In our R&E evaluation activity that turns out its products (new knowledge) in an environment that is, if not sterile of complicating factors, certainly "least squares." Yet, we expect our products to be used in a decidedly untidy environment. We surely are at a sufficiently advanced stage in the growth and development of our R&E evaluation methods that we can take time to rethink our posture about this R&E evaluation environment, to consider what it needs, how what we have already done fits into these needs, and how we can assign the task among ourselves according to abilities to best get the job done. It will take some hard soul searching for some of us, including a reassessment of our primary motivations and the appropriateness of our reward system in our discipline and professional circles and a real assessment of the impact of the rational structure of our economic theories on what we do and how we do it.

The informational environment associated with research administration and policymaking is getting increasingly more complex. The science we deal with is more sophisticated now than in the past, meaning that the margins we can work with have increasingly less room to tolerate error and wrong decisions are more costly. There are more factors to be considered in making our judgments about the right thing to do, and these decisions are more interlocking. Further, there is almost negligible time between such decisions and the first felt impacts of those decisions. Decisions must be made more quickly, more precisely, and be more reliable--reliable in the sense that what results from that decision most often corresponds with our expectations about that result.

This has two important implications to advisors of these policy and resource allocation decision processes. First, greater emphasis must be placed on the analytical frameworks in which measures of research impact are used to produce the intermediate knowledge to which Wright refers. Data generation and analysis schemes must be tied closely to these frameworks to permit better identification and specification of variables and an improved feedback to experts about the relevance of what they are providing. Second, experts will need to focus even more than in the past on educating policy and decisionmakers, not about methodologies and appropriateness of data provided, but about the significance of factors and relationships those data reveal. Unfortunately, substantial decisions will still tend to be made on the spur of the moment. The most appropriate information at those moments is not tables and graphs but that knowledge tucked in the back of a policy or decisionmaker's mind.

the research performing organizations themselves the function of handling research evaluation information. The principal benefits come in being able to tie various decentralized and highly disjointed efforts together to provide the intermediate knowledge linkage previously described. Whether this is occurring because administrators and policymakers are becoming more sophisticated in their decision processes or are acting more out of desperation to the complexity of information requirements described above is not really important. With the right people in the staff groups and on the various planning committees, the job will get done.

At the same time, I would offer a precaution. The close association with scientists that I have experienced over the past few years has given me a changed perspective of the research administration process. It has resulted in an awareness of the fact that we do need to be "opportunistic." We do not dare to overload the research system with so much information on measures of research benefits and costs, especially in light of the increasing management orientation that prevails, that we stifle opportunism as a working philosophy. Science always has been and will always be a highly creative process. Breakthroughs that can cause discontinuities in our measures of gain in productivity cannot be anticipated or indexed. The purpose of our exercises must be attuned to the role of helping to anticipate the future and the options open to resource allocators. It is not the drafting of rigid blueprints. Our methods and techniques and our expectations regarding their use as reflected in how we present the results of our analysis must be designed to this end.

With respect to methodology of measuring research benefits, the ex post analysis school and the ex ante analysis school have generally been going their own ways, often with some rancor between them. In the future, it will not be a question of the one or the other; the results of both types of analysis are and will continue to be needed. The one can provide the basic understanding of research and technology processes as well as base line estimates of gains. The other can provide forward looking estimates of gain in the context of highly judgmental circumstances and at considerably less aggregated levels. Also, as statistical estimation is being improved by the hybridization of Fisherian statistics and Baysian statistics, so also will resource allocation and policymaking information be improved by the hybridization of ex post and ex ante analysis methodologies.

Finally, I believe there is an ultimate challenge which the community of researchers who conduct R&E evaluation studies must face. It sorts of approaches and methodologies as we have in the past, using the current groundswell of concern to support these efforts, yet largely disregarding the relative degree of relevance of these efforts to actual information needs. The challenge is to step back and critically evaluate what is being done, to question whether past approaches are as relevant as they once were (a hypothesis not a conclusion), to consider that we might even need to change our whole approach to measuring the product of research. Do we only keep pecking away at interesting, possibly important, issues related to our understanding of the research and technology adoption processes, or do we also commit ourselves to helping anticipate as best we can the future of research-related challenges and then try to guide the system in what we anticipate to be the most effective direction? I don't believe both of these approaches can be accommodated as a single goal. Certainly, the one is much more comfortable, but the second is more useful and productive in the long run.

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EVALUATION INFORMATION ON AGRICULTURAL RESEARCH

Molly Frantz*

As one of your lead-off speakers, my task is to give you one user's perspective on the need for evaluation information in making decisions affecting agriculture research and development. This is not to imply that agricultural research and development policy decisions are made in isolation. Far from it; these decisions are made in the context of overall agricultural policy objectives. With that said, let me tell you the points my brief remarks will cover. I hope to give you first, a feel for:

1. The OMB perspective with respect to its role in the federal decision-making process. I will try to give you a feel for the organization, the way in which it works, and OMB's purpose.
2. The context in which OMB uses evaluation information.
3. My assessment of the current evaluation information efforts with respect to agricultural research.

The OMB Perspective

Organization

OMB is a major player in the development and implementation of broad presidential policies. OMB's role is principally to coordinate the interests of the concerned agencies and to see that any proposals are consistent with either past administration positions or new administration policies or both. On occasion, OMB proposes alternative courses of action.

Like other executive offices of the president (EOP), OMB functions as staff to the president. But unlike these other EOP offices, OMB is predominately staffed with career civil servants. As a result, OMB is relatively unencumbered in its role because of this degree of isolation from constituency interests. Consequently, we do not perform an advocacy function, although we often are thrust into an adversarial role.

Means

OMB is near the apex of the executive branch's decision-making pyramid. As such, OMB has access to virtually all of the decisionmaking "levers" within the federal government. These levers, or functions, are: the formulation of the budget request to Congress, the clearance of legislation, the clearance of major reports which have policy implications, the oversight of regulations, the clearance of data-gathering instruments (forms clearance), and the review of agency fiscal and management operations. With the exception of the last two items, forms clearance and operations, all of the other functions involve the preparation of policy documents.

Purpose

OMB analysis has one overriding purpose--to determine what the federal role in "X" should be. This fundamental purpose can be broken down into three key questions:

Is there a reason for federal involvement?
How extensive should that involvement be?
What form should that involvement take?

A highly simplified example applying these questions is illustrated by the decision to initiate a competitive basic plant research grant program in USDA.

Is there sufficient justification for federal participation in plant research?

How direct or indirect should the federal support be, vis-a-vis the states and the private sector? Also, should that support be directed at all aspects of plant research or just at particular aspects; i.e., just at basic research on nitrogen fixation? What would be the best means for ensuring that the objectives of the federal program are met; for example, should the funds be targeted to all the qualified researchers or just a segment of those researchers?

The Context in Which OMB Uses Evaluation Information

OMB has two principal evaluation focuses for every program: (1) How effectively does the program meet its immediate objectives? (2) How

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*Office of Management and Budget, Washington, D.C. The opinions expressed here are those of the author and not the Office of Management and Budget.

underlying rationale for federal involvement in the identified problem area and the problem's sufficient priority relative to all the other problem areas.

The typical questions regarding the first focus, the effectiveness of agricultural research, would be:

How effectively are the formula funds distributed with respect to "priority" research goals?

What should be the proper balance between intramural research and extramural research?

The products of your work apply more often to the second focus, the contribution of agricultural research to broad agricultural policy objectives. Questions of interest here might be:

What are the opportunity costs involved in emphasizing agricultural research over some other form of assistance, such as dissemination of information, financial incentives or regulations?

How obtainable is the objective through research, vis-a-vis some other mechanism?

OMB looks for variety of criteria to measure program outputs. They all can be articulated in terms of efficiencies, but not necessarily in terms of dollars and cents. Said another way, research (including agricultural research) is assessed on the basis of its economic and social consequences.

Assessment of Current Evaluation Information Efforts

Within the context of the preceding remarks, I would now like to deal with the two questions posed to me by Dr. Fishel:

Are the current evaluations of agricultural research of any use?

What kind of information is needed to make better allocation decisions?

To be honest, I have not found very much of the current evaluation data influential in making decisions to allocate resources to and within agricultural research, at least at the OMB level. This is mainly for two reasons. First, I generally rely on the Department of Agriculture's ranking of research activities as a more broadly based reflection of national research priority needs. Second, the bulk of the available evaluations do not address the diversity of non-economic criteria used at OMB in making resource allocation decisions.

The evaluations I see tend to be of a singular focus, generally economic in nature and primarily dealing with "rate of return" data. It is impressive to know that the average rate of return on all of agricultural research expenditures is estimated to be between 25 and 55% for every dollar spent. But what does this mean in terms meeting such national objectives as creating a positive balance-of-trade position, improving the quality of the environment, adding to the general health and safety of the population, and enhancing the general quality of life of the population.

The current agricultural research evaluation efforts provide only a myopic view of a program's accomplishments. When one restricts himself or herself to such a narrow evaluation base, that person runs the risk of saying nothing or very little about the fundamental questions of need and the appropriate federal role. It is clear that the role of the federal government is not to turn a "profit" -- we have the private sector for that. Just think what the lost opportunity costs would be, both in economic and social terms, if we were to fund only those programs with high rates of return? Would defense spending fare as well? What about medicare and medicaid spending? Has agricultural research nothing else going for it except its "rate of return"? I do not think so, but evidently the research community does.

My widget analogy states that just because great widgets can be produced economically does not mean that tax dollars should automatically be used to support that effort. There has to be a need for those widgets.

Conclusion

Let me conclude my remarks by saying that I am encouraged by some of the evaluation work being undertaken right now. There is attention being given to more broadly defining the effectiveness of agricultural research--and extension I might add--as well as to the contribution that research makes to achieving national priorities. However, attention also needs to be focused on the trade-offs between various means of addressing a national problem, i.e., research versus the dissemination of information versus financial incentives, etc.

Everything I have been discussing in the preceding speaks to the long and short-range planning of agricultural research. You are all aware of the significant and legitimate questions that have been raised about the way the agricultural research community prioritizes its activities. What should or can be done to change this process? Evaluation information is the key to that question and to your concern about how resources will be allocated in the future. The golden days of the sixties and the early seventies are gone. Unfunded, economically defensible research opportunities are and will continue to be more prevalent unless the agricultural research community directly addresses the concerns of policymakers.

The burden of proof is on the agricultural research community to demonstrate why a long-term investment of federal dollars is more desirable than the benefits of short-term program expenditures.

RESEARCH EVALUATION - THE NEEDS OF AN ADMINISTRATOR

Raymond J. Miller*

Agricultural research and the so-called agriculture establishment have been evaluated over a period of years by different groups and in different ways. At times it seems as though there are more criticisms than positive statements. Why this happens is not clear, but some of the fault rests with us. There are a number of studies that could be conducted to bring a better perspective to the benefits or lack thereof of agricultural research.

In this paper, I'll outline some of the evaluations and research that could be conducted that would help put agricultural research and its methods in perspective with other research management systems and some of the types of evaluations that I need as a research administrator.

The Agriculture Research and Education System

Before we can discuss the evaluation of a system and whether or not it can be improved, the system must be understood. Without that understanding it is difficult, if not impossible, to conduct proper studies to determine if there are models in existence which will allow us to perform better.

Agricultural research is really an applied science. It draws upon the knowledge developed by chemists, physicists, etc. and applies it to agricultural problems. Sometimes that fundamental knowledge isn't available so we have to conduct the research. As a result, most agricultural programs will have a wide spectrum of research programs. Since we have the responsibility of providing information that solves or prevents agricultural problems, we have an array of interacting disciplines in our departments or units. These problems should provide an interactive system ranging from the application of knowledge to fundamental research going through the often described stages from the user, to the county agent, to the extension specialist, to applied research, to developmental research, and finally to fundamental research. As you move along this spectrum, each step becomes more specialized and, therefore, will have more components. The agent and the user have in many ways the most complex task as they are the integrators of a large amount of information. They must be properly trained so they can assimilate, understand, and apply the results of research. Thus, formal teaching, extension and research are interlocking. This is why the U.S. system has been so productive.

Evaluation of Needs

1. Comparative analysis

If the U.S. agricultural system is so good yet is so widely criticized, why hasn't its productivity been compared to that of other countries such as Canada, Great Britain, Germany, USSR, etc.? Similarly, if the agricultural research system is so poorly managed and so unproductive as some say (which I don't believe), why hasn't agriculture been analytically compared to NSF, NIH, Interior or other agencies? I believe agricultural research would come out on top or very near it in such an analysis.

2. Competitive funding

Many people seem to think that the best research (most productive) is that which is conducted under competitive funding programs. Some competition is good but several important factors are often overlooked.

(a) People who become scientists have a wide range of personalities. Some of them will do well in competition and some of them will not and will avoid it, yet some of the latter are outstanding scientists.

(b) Some areas of science that are necessary are not suitable for competitive funds, i.e., long-term plant or animal breeding programs.

(c) Many scientists and administrators think formula funds are wrong, but they are part of a base program. Many other funds fall in the same category, i.e., state general revenue funds to institutions of higher education; but are they discussed in the same way?

(d) Maybe the most important factor is how much

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to be determined. Remember research is a creative activity; the attitude of the performer is crucial.

(e) Non-competitive funding provides a solid, long-term base of research support upon which a more stable research program may be developed. Competitive grants programs may then to used to complement, and add to an established, productive research program.

3. Support allocation

There is a fairly good correlation between the dollar importance of a commodity and the research support allocated to it. But did that support come because of the pressure generated by the commodity size or did the commodity become large because of research? I can guess which came first but it would be good to know for sure.

More importantly, many of our direct diet foods have serious production problems. These show up as yield plateaus or declining yields. Most of these commodities are produced on relatively small acreages and have a small national dollar value, yet are very important to our diets. We need to know what potential payoff there is with different levels of investment. Based on such things as the genetic potential needed to solve problems, there should be enough information from corn, wheat, soybeans, etc., so that you could develop a good predictive model as to the potential of success, the information gaps and approximate resources needed. Such information would really help all of us in our research planning.

4. Production functions

Agricultural economists should have been at the forefront of developing responsive up-to-date production functions. Now that they are desperately needed, they are not available.

Over the last few years, the biological and physical scientists have developed a number of physiological models. Can we use them to obtain production functions? If not, how do they need to be modified?

5. Problem analysis

As administrators, we have to continually make judgements as to how important or serious a problem is. Many times, we haven't been provided with the information to help make objective decisions. For example:

(a) How damaging are weeds and what is the potential loss due to a new invading species?

(b) Food loss beyond the farm gate--how bad is it and what would the consequences be if it were reduced?

(c) What is the relationship between cosmetics and price?

(d) Soil loss--we hear a lot about soil loss due to erosion and growth. But how bad is it in terms of our long-term production base? If it is of the greatest is in the size and efficiency of farm equipment. What is its impact, not just on the economics of farming but on such things as erosion and size of farms and what would be the consequence if different types of equipment were available now?

(f) Changes in the beef industry--There are several indicators that with time the beef industry will change particularly toward shorter, if any, time in feed lots. What are the implications on the animal and the feed industries?

(g) Production shifts--For some time this country has grown products where the climate, the soil, isolation and factors were optimum. The products are then shipped to market sometimes long distances. With increased fuel costs, these days may be over. Will production areas shift? Will most products be more on a local basis? If so, what are the implications and how could we allow an orderly change?

(h) The value of a university education--For years, we have said a university education was important, because it increased earning power. That is not necessarily true. What is the value of an education to the recipient, the state, and the nation?

6. Decisions in a vacuum

Many decisions and policies are based on perceptions rather than fact. If the facts are not available, what else can be done? You have not been leaders; you have been responders. You people need to be developing the alternative information before, not after, laws, policies, and action are taken.

Let me close with a few observations that are important to agriculture but more specifically to agricultural economists. If, as you so often tell me, the country has underinvested in agricultural research, why do we have such terrible prices? What would the consequences have been if there had been a greater investment? A lesser investment?

When you do your analysis, don't forget that scientific knowledge is cumulative and comes in stepwise increments. There is seldom, if ever, a major breakthrough. It may appear that way but it is really the aggregation of many small details. This implies that there is a need for many performers in the same area. This is true to a degree but scientists have a habit of following trends and spending too much time fine tuning or applying techniques to additional areas when extrapolation would be adequate.

In any evaluation, remember that the United States is a large heterogeneous country and aggregate evaluations may not be adequate. There are state and regional needs.

come by, no matter what the data says.

As a profession, you have a major hurdle to overcome. You have to learn to work with other scientists. It takes time and effort but until you do, your work won't be nearly as effective as it could be. In other words, don't talk to yourselves so much!

EVALUATING FOOD AND AGRICULTURAL RESEARCH FOR THE CONGRESS

Richard D. Lieberman*

Every time someone asks me about federal "program evaluation" of late, a funny image comes into my mind of a man running on a treadmill, hooked up to all kinds of wires and electrodes, with air being supplied through a mask so it can be carefully monitored. It often seems that the people who want program evaluation would like to "instrument" the federal program in question, and reach some kind of scientific conclusion on what it is really doing. If we could do that effectively for all federal programs, and determine legitimate and comparable benefits and costs, we might be able to rank-order by benefit/cost ratio all federal programs and eliminate our problems in balancing the federal budget. We would simply cut off at the "balanced budget level" funds for programs that were below a certain benefit/cost ratio. Having proposed this wonderful utopia, I need only remind you that our abilities to evaluate federal programs are nowhere near sophisticated enough to make it work. Even if they were, the American political system would find a way to circumvent such a system by creating a sort of "tax code" for program evaluation that would inevitably be riddled with loopholes and exceptions.

Before going any further, I should probably reveal some of my intellectual biases in this whole matter. I have always harbored suspicions about program evaluations, because they tend to be done by economists, and I have never been convinced that economists had the best answers to very many things. They seem to suffer from the flaw that Harry S. Truman implied when he asked his staff to find him a one-armed economist--someone who couldn't say: "on the one hand...on the other hand..." But I have resolved myself to the notion that economists shall do program evaluations, because most of the alternatives--including the one that political scientists shall do them--are even less palatable. Notwithstanding everything that has happened in the social sciences over the past 30 years, I still view politics or government as more "political fiction" than "political science."

Before getting any deeper in an interdisciplinary squabble, it will suffice to say that it really doesn't matter who does evaluations, as long as they are done in some kind of reasonable manner.

Now, just what is a reasonable manner? First, you should recognize that I am talking about what is reasonable for the Congress. There may be different standards set by professional evaluation associations, but there clearly are some basic guidelines that one should follow when doing something which has Congress as its ultimate user.

What does Congress need in order to make informed judgments about how to structure programs, how to change them and how much money to provide them. It seems to me there are five basic rules that must be followed:

Rule 1: Evaluations need to be understandable to the average layman.
Rule 2: Evaluations need to be scientifically defensible.
Rule 3: Evaluations need to reflect what is going on in the program as a whole, not what is happening in some isolated instance or area.
Rule 4: Evaluations need to be timely.
Rule 5: Evaluations need to be succinct or summarized.

Expanding a bit on each rule outlined above could help clarify.

First, evaluations must be understandable. They must be pursued in a common sense way. Basic questions must be clearly laid out in a simple way, so that someone who knows little or nothing about the program being evaluated can understand what it was intended to accomplish and how you are going to measure that. The criterion I use is this: Could you explain the evaluation in a period of not longer than five minutes to a group of 10 Senators with diverse backgrounds, in such a way that they would understand what you did and what you found?

Evaluations of federal programs should start with the basic program goals as stated in the original legislation that created it. In cases

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the question of whether it achieved those goals and objectives and how you measure that can be addressed.

Second, evaluations must be scientifically defensible. Although scientists and social scientists in particular often disagree, the evaluation must not suffer from procedural or methodological flaws that make it a helpless victim of relatively modest criticism. This sounds like it is so obvious it's trivial. But bear in mind that if decisionmakers in Washington, who know little about how evaluations are conducted from a technical standpoint, can find procedural or methodological flaws in it (read that: things that don't stand the test of common sense), your study will have little value. And there appears to be a variety of policy analysts developing around the federal government who are likely to get rich from critical analyses of botched evaluations, if they can present their criticism in a persuasive way.

Third, evaluations must reflect the program as a whole. It is not particularly useful, from the perspective of the Washington decisionmaker, to know that a program in Marshfield, Wisconsin, is working when you're not sure it's working as well 60 miles away in Stevens Point, or across the Minnesota border in Red Wing. Certainly, evaluations of pilot projects make sense. But remember that Congress makes decisions about programs in the aggregate, so your evaluation should say something about that. Methodology should support legitimate extrapolations and general conclusions.

Fourth, evaluations must be timely. It may sound strange to maintain that Congress is an institution where time is of the essence--after all, it is reported that Mark Russell once said that the only thing Congress can get done in 10 days is make Minute Rice. But, the point is simply that a thorough evaluation coming three weeks after the House and Senate have acted on the current appropriation or authorizing legislation would be of little value. A less complete, but still valid evaluation that came three weeks earlier would be of far greater value.

Fifth, and finally, evaluations must be succinct. You must be able to summarize your evaluation in a meaningful fashion. Studies that are too long tend to be ignored and consigned to the trash heap. No matter how long or involved the study actually was, a good summary is essential for meaningful Congressional deliberation.

The mission assigned to the Joint Council on Food and Agricultural Sciences by Section 1497 programs conducted in the United States" is no small task. This charge was put in the law, because the Congress felt that it needed to have such evaluations and was not particularly happy with those that had been conducted in the past. And, Congress believed that the evaluations needed the kind of national and diversified perspective that could only be provided through an organization like the Joint Council.

Although I can't tell you how to conduct evaluations, I can assure you that Congress will not be well served and will be little influenced by them unless they are understandable, scientifically defensible, reflect the program in the entire nation, and are provided in a timely fashion and in a succinct enough form so that they fit into our present legislative process.

REVIEW OF METHODS USED TO EVALUATE RETURNS TO AGRICULTURAL RESEARCH

George W. Norton and Jeffrey S. Davis*

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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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.

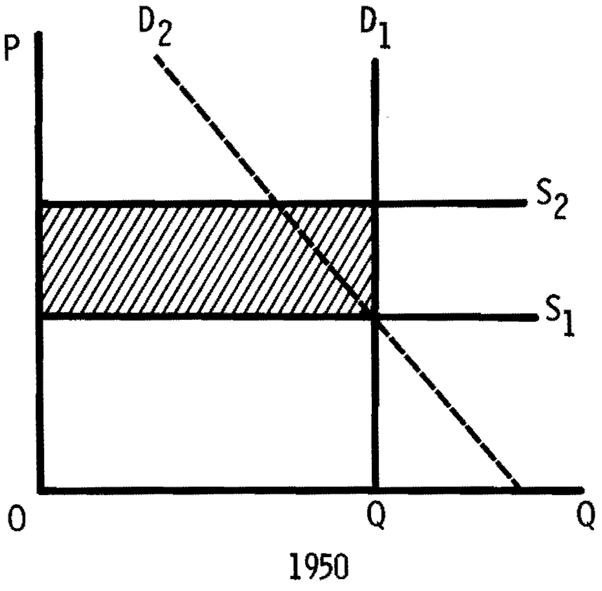
Consumer and Producer Surplus Approach 4/5/

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 demand elasticity was minus one. In Figure 2, the increase in consumer surplus equals E + F which equals $K\ P_1Q_1\ (1 - 1/2Kn)$ 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 = $K\ P_1Q_1\ (1 + 1/2\ \frac{K}{n})$ 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:

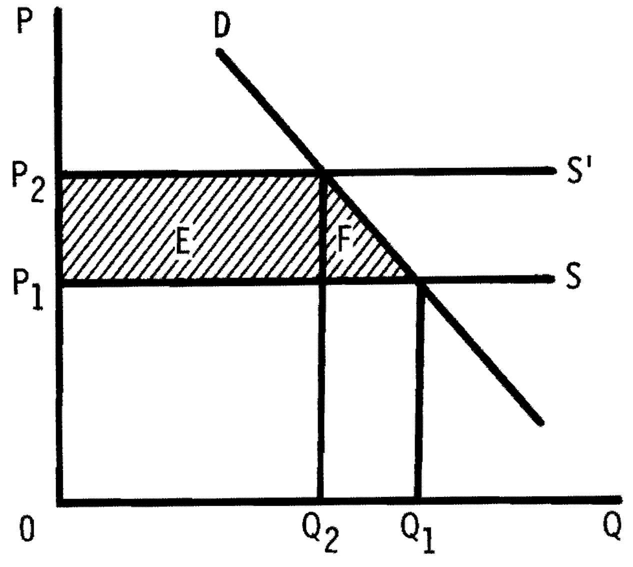
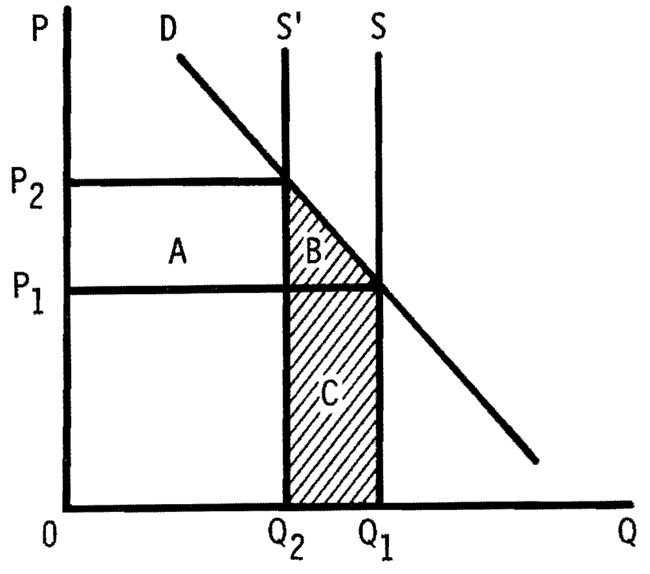
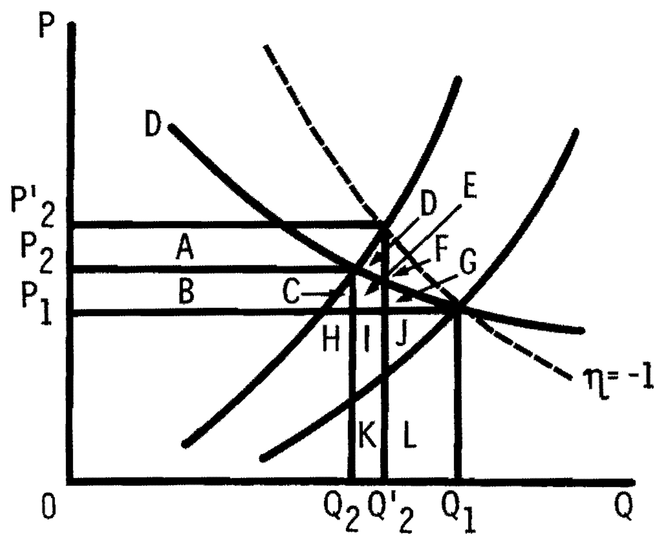


Figure 3.





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

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

(2) $KQ_1P_1(1 + K/2n)$ if n = 1 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) Total net social surplus = $KP_1Q_1\ (1 + 1/2\ \frac{K}{n+e})$

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

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

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 tion for the displaced farmworkers.

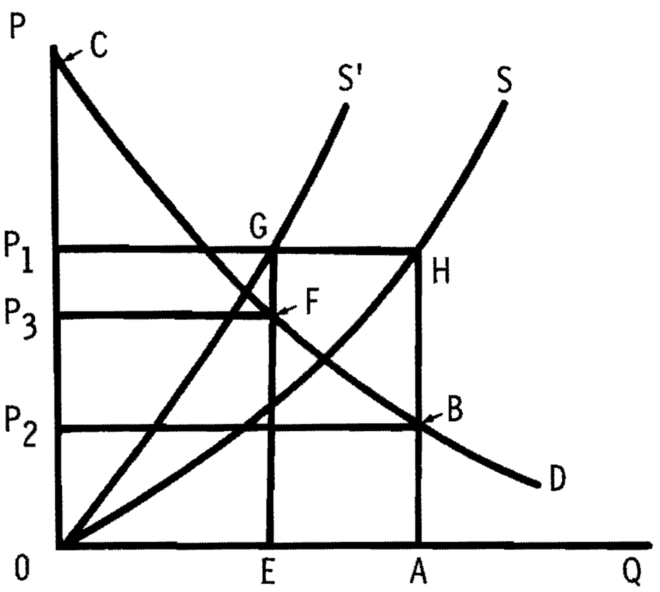
Ayer and Schuh (1972) altered the model to incorporate a cobweb behavioral assumption for cotton production in Brazil. The change in social returns equals (OABC - OAH) - (OEFC - OEG) in Figure 5 where S equals supply of cotton fiber when improved varieties are planted, S' equals supply of cotton fiber 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 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:

Figure 5.

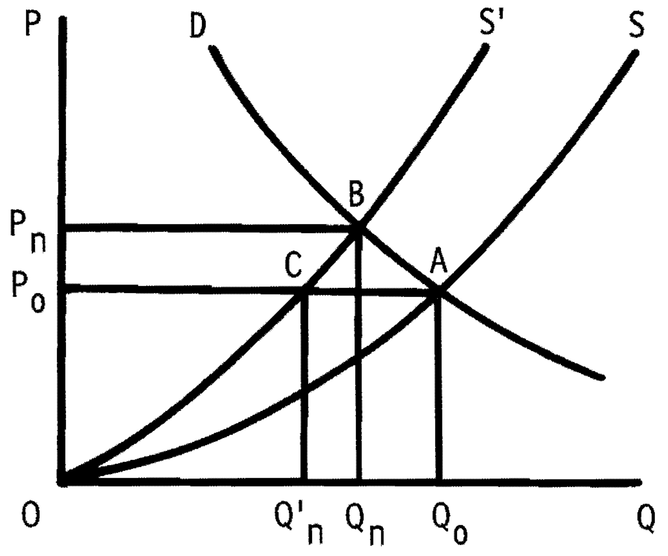


$$(D)\, d\, (Q) + \int_0^E (S')\, d\, (Q).$$

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 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 $ACQ_n'Q_o$ 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 $ACQ_n'Q_o$:

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

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

$$(9)\ AOC = KP_oQ_o$$

$$(10)\ ACQ_n'Q_o = (1+e)KP_oQ_o$$

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.

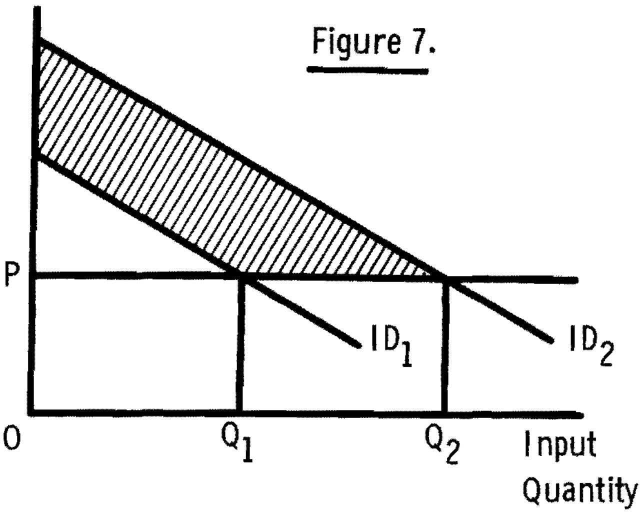
Duncan (1972a, b) used the consumer-producer surplus approach in a somewhat different manner. He estimated the benefits of research that increases the productivity of a product which, in turn, is an input into the production of another commodity (i.e., the demand for the product is a derived demand). 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:

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

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

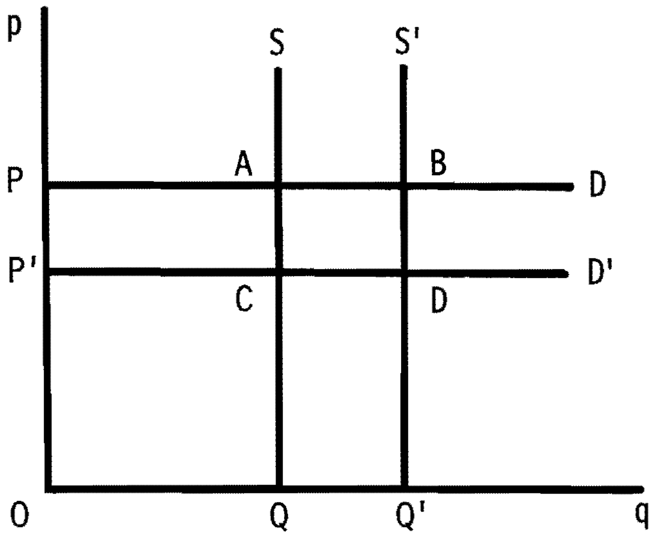
Figure 7.



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



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

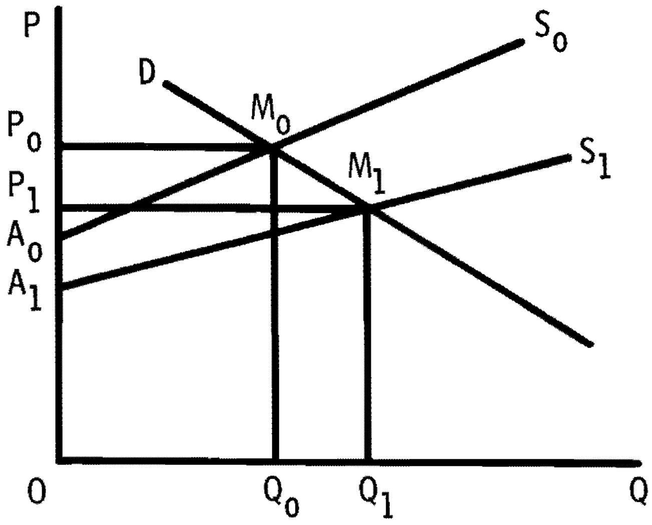
(12) change in total benefits ($A_1M_1M_oA_o$) = 1/2 ($P_oQ_1 - P_1Q_o + Q_oA_o - Q_1A_1$),

(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 ($P_oQ_1 - P_1Q_o + P_oQ_o - P_1Q_1$).

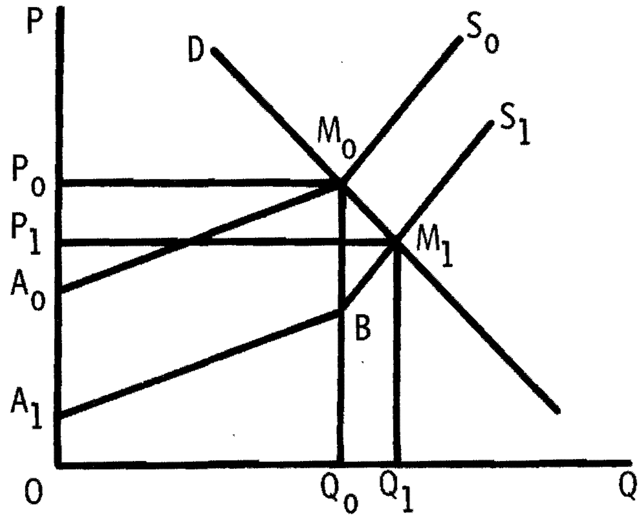
P_o and Q_o are current price and quantity, $P_1 = P_o\,(1-\frac{ke}{e+n})$, $Q_1 = Q_o\,(1+\frac{ken}{e+n})$ where k is the absolute cost reduction at Q_o divided by P_o, $A_1 = A_o/(1-k)$ for a proportional shift, $A_1 = A_o - R$ where R is the absolute reduction in average costs for all firms for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

Figure 9.



(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:

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

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

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

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

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

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 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 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.

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

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,

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

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

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 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 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

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 rowing 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

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 tical 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

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 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.

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 *ex ante* 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 *ex ante* 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 *ex post* 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

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 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.

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).

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 citly, 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

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

	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 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.

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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EVALUATION OF AGRICULTURAL RESEARCH:
PROGRAM EVALUATION METHODS AND APPROACHES

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Introduction

This paper examines the evaluation of agricultural research from a program evaluation perspective. The primary focus of the paper is to provide an overview of the various approaches and methodologies that are available for the evaluation of agricultural research programs--including program processes and past, current, and future impacts. Many of the approaches and methodologies that are available are not used for the evaluation of agricultural research. They are used by evaluators from outside the agricultural research community for the evaluation of non-agricultural research and technology programs. Program evaluation as an approach is differentiated in this paper from evaluation research by its emphasis on programs and on the usefulness of analytical results for decisions about programs. Philip Olson {11} makes a similar distinction between policy research and applied research in the field of rural sociology; this categorization can be used as well in the area of economics. The evaluation literature about agricultural research has been described by George Norton and Jeffrey Davis {10}. Much of this literature, especially in the area of ex post evaluation, is evaluation research--evaluation studies that are divorced from the decisionmaking process about agricultural research programs.

Program evaluation can address decisions about developing, adjusting, and improving programs--formative evaluation--and decisions about the worth of continuing or beginning programs--summative evaluation {13}. This emphasis in program evaluation on the use of findings for decisionmaking tends to lead to studies concerned with methodologies and approaches for informing decisions about current and future programs, rather than decisions about the processes and impacts of past programs.

This paper will first review a number of the analytical approaches used to evaluate research, technology, and other programs. It will then examine several of the issues influencing the applications of program evaluation methodologies in agricultural research and suggest possible approaches for addressing those issues.

Program Evaluation--Approaches and Techniques

Many different terms are used to describe analyses of program processes and impacts that are conducted in support of decisions about research and technology programs. Coates {4} provides a list of some of the terms. A modified version of that list is shown in Table I. Applicable terms vary from the term program evaluation used in this paper to technology assessment, policy analysis, and social impact assessment. Different terms are used in different agencies and by people from different disciplinary backgrounds. The central features of all these approaches are that they are analyses of program processes and impacts designed to inform decisions about programs.

Coates {4} also provides a list of techniques used in analyzing programs based on a survey of practitioners of program evaluation, technology assessment and other similar analytical approaches applied to research and technology programs. The survey results provide a good representation of the various techniques used in program evaluation and are shown in Table II. They include quantitative and qualitative techniques. The collection of program data and information through interviews, observation, analysis of background data, expert opinion and consensual techniques is involved in many program evaluations. Modeling, simulation, statistical analysis and other quantification techniques are used. Informed judgment is used as a technique by most evaluators.

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Policy Analysis
Program Analysis
Policy Research
Futures Analysis
Technology Assessment
Priorities Analysis
Integrated Technology Assessment
Impact Assessment
Social Impact Assessment
Environmental Impact Assessment
Comprehensive Impact Assessment
Secondary Impact Analysis
Policy Assessment
Policy Alternatives Assessment
Evaluation
Situation Assessment
Strategy Assessment
Technical Program Assessment
National Assessment
Program Impact Evaluation
Comprehensive Technology Forecast
Comprehensive Planning
Socioeconomic Studies
Socioeconomic Profile
Ethnodocumentary Approach

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*Adapted from Coates {4}, Vol. I, List C, p. 147.

Analytical Approaches*

Informed Judgment
Modeling
Consultation with Experts
Cost-Benefit Analysis
Workshops, Panels, Conferences
Input-Output Analysis
Statistical Analysis
Scenario Writing
Trend Analysis
Cost Effectiveness Analysis
Public Participation
Interviews and Opinion Surveys
Decision Analysis
Cross-Impact or Cross-Support Matrix
Historical Analog
Simulation, Gaming
Delphi
Probability Tree
Relevance Tree
Rank Size Analysis
Substitution Curves
Mophological Box
Stochastic Estimates
Least Cost
Signed Digraph
Network Analysis
Content Analysis
Ecosystem Analysis

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*Adapted from Coates {4}, Vol. I, p. 164.

A sense of the range of approaches and techniques used for program evaluation can be obtained from the recent literature surrounding program analyses of the application of innovations in various areas. Three examples from outside the agricultural research area are discussed in the remainder of this section--energy development, population planning, and education innovation. Many of the evaluation techniques used in these areas are also applicable to agricultural research programs.

Evaluations of energy development programs have been a highly visible feature of energy policy discussions since the 1973 oil embargo. An extensive literature on boomtown studies resulted from the concerns expressed in the 1970s about the socioeconomic and environmental impacts on communities of oil, coal, nuclear, and solar energy development programs {8}. Techniques used in these studies include qualitative analyses based on judgment and expert opinion, surveys and statistical analysis, and socioeconomic and environmental impact and simulation models. A unique characteristic of the boomtown studies, compared to much of the program evaluation literature in other areas, is the focus on communities and relatively small geographic areas.

Population and family planning programs in developing countries were heavily funded by the U.S. Agency for International Development, the United Nations, and the World Bank during the 1960s and 1970s. Evaluation studies were a key element in many of those programs. Evaluation methodologies used in the studies include benefit-cost techniques based on survey or other data and socioeconomic-demographic simulation models {1}. Detailed socioeconomic and demographic impact data, usually at the national level, are analyzed. Support for and interest in population programs and their evaluation declined sharply after the United Nations World Population Conference in Bucharest in 1974.

Demands by the congressional and executive branches for evaluation of the many new education programs introduced in the 1960s was an important source of the emergence of program evaluation as an academic discipline in the late 1960s and 1970s. Evaluation in education appears to have been less constrained by disciplinary traditions than in other fields and a number of methodological developments have originated in the and experimental techniques adapted from agricultural research experimentation to the methods of anthropology and ethnology involving observation, interviews, questionnaires, and analyses of program documents and background information {12, 13}.

Evaluation of Agricultural Research

This Symposium on Methodology for Evaluation of Agricultural Research is an outgrowth of changes, beginning in the 1960s that have affected the entire scientific community. Several factors have led to requirememts for public participation in decisions about federal research and technology programs, greater public disclosure of government information about programs, and expanded efforts to examine the potential future impacts of technology. These factors include a growing assertiveness of the Congress relative to the executive branch; greater sophistication and understanding by the public about technology; and growing public suspicion of the government and of research and technology programs {4, 11}. The consideration of impacts in federal funding decisions has expanded beyond the scientific, engineering, and economic feasibility of technologies to include broader economic, social, and environmental impacts {9}. Federal requirements for environmental impact statements have been applied to research and technology programs in a manner that involves considerations of socioeconomic and community impacts as well as physical environmental effects. The use of economic, social, and environmental impact information in decisions about federal agricultural research programs is specifically addressed in Title XIV of the Food and Agriculture Act of 1977.

Because of the nature of the agricultural research process and the events leading to the growing demand for evaluation of agricultural research, methodologies and techniques for the evaluation of agricultural research must enable the evaluator to address the following issues:

- utilization of evaluation results by decisionmakers;
- the process or stages through which research is transformed into technologies or innovations and diffused and marketed;
- estimates of economic, social, environmental, human nutrition and health, community and other impacts;
- public participation in the evaluation process; and
- sources of bias in evaluations.

The remainder of this section of the paper examines possible methodologies and techniques that are available to begin to treat some aspects of these issues. This listing of methodologies is

There is ample opportunity for the creation of new and improved methods to evaluate agricultural research programs.

The traditional model of agricultural research and technology programs is one of sequential stages of mission and non-mission oriented research, development of technology, and diffusion (adoption, commercialization, and/or utilization) through extension, formal education and other means. There is surprisingly little formal evaluation of the agricultural research and technology process, and in particular, the linkages among research, extension, and education programs. Some of the best information is available in retrospective or historical case studies supported by the National Science Foundation that document significant technical and nontechnical events for a series of technological innovations {6}. Diffusion of agricultural technologies must occur for them to have impacts. Kevin Goss {5} suggests a framework for treating the impacts or consequences of agricultural innovations that includes the levels of impact measures and the distribution of those impacts among the population. He classifies impacts as desirable or undesirable, anticipated or unanticipated, and direct or indirect impacts.

Two basic approaches can be followed to develop data for the evaluation of agricultural research programs to inform the decisionmaking process:

(1) simulation modeling of program processes and impacts, and

(2) collection and analysis of process and impact data for particular programs.

Yao-chi Lu {7} and others (for example, see Norton and Davis {10}) describe models for simulating various impacts of agricultural research expenditures in ways that permit varying assumptions about the innovation process. Comprehensive models to consider economic, social, and environmental impacts of agricultural research programs are not being used at this time. Such models have been assembled for use in other areas, for example in the analysis of energy policy by the Energy Information Administration of the Department of Energy {2}. Household-level microsimulation models are especially promising as a means of estimating distributional patterns of impacts among households with varying income, race, occupational, and other characteristics {2}.

In many instances, comprehensive models and data to evaluate agricultural research programs will not be available. The only possible approach is to develop an evaluation design that applies to the policies and issues which are relevant to the program and that incorporates necessary data collection and analysis techniques. The collection of both qualitative and quantitative data is likely to be involved.

be the most appropriate approach {3, 6, 14}.

Joseph Wholey {16} suggests the use of evaluability assessment, rapid-feedback evaluation, and performance monitoring as evaluation methodologies designed to involve decisionmakers in the evaluation process and thus to improve the usefulness of program evaluation results. These methods are viewed by Wholey as possible sequential steps in the evaluation process that could culminate, when appropriate, in a more intensive evaluation of program impacts and their causes. Evaluability assessment has received especially favorable attention as a program evaluation technique in the last several years by federal agencies and congressional staffs concerned with program evaluation. A modified version of evaluability assessment is incorporated in the design for the evaluation of the Expanded Food and Nutrition Education Program (EFNEP) being conducted currently in the Science and Education Administration of USDA.

Perceptions about the objectivity and independence of an evaluation and the likelihood that an evaluation will be used for program decisions are interrelated both with the extent of public participation and the participation of program managers and decisionmakers in the evaluation process. The scope of participants in the decisionmaking process in the food and agricultural sciences has expanded rapidly in recent years {9}. The decisionmakers in the food and agricultural sciences now include federal, state, and private providers of funds; federal, state, university, and private sector performers of agricultural science; users of research, extension, and teaching services; and people and institutions impacted by the food and agriculture sciences. Participants in the decisionmaking process are also stakeholders in the quality and objectivity of evaluations of agricultural research. Perceptions about the objectivity of an evaluation and its usefulness for decisionmaking are often affected by the extent to which various groups of stakeholders participate in that evaluation and the availability of information about it. Stakeholder-based evaluation is being tested by the National Institute of Education as a strategy to obtain greater utilization of findings from evaluations of pilot and experimental education programs. This approach was suggested in a paper by Stephen Weiner and associates {15} and incorporates an intensive involvement of the evaluation team with stakeholder groups throughout the evaluation process.

No evaluator can be totally free of bias, even when conducting a highly quantitative, totally reproducible evaluation that excludes all judgment. Michael Scriven describes several arrangements to offset or reduce evaluator bias {13, of the evaluation, and the use of institutional guarantees of independence through insuring ignorance of various sources of biased information or through the availability of countervailing bias. Possible techniques to reduce bias include:

- metaevaluations--the evaluation of evaluations and evaluators through evaluation replication or the use of stakeholders or others as metaevaluators;

- standardized checklists of the characteristics of high-quality evaluations;

- improved training and education of evaluators;

- use of external evaluators, whenever possible; and

- goal-free evaluation--the initial development of the evaluation design without knowledge of program goals in order to consider the broadest possible range of unintended and intended impacts {13}.

Concluding Comments

The purpose of agricultural research evaluation is to inform the decisionmaking process as completely as possible about the economic, social, environmental, human nutrition and health, and other impacts of agricultural research programs in the past, present, and future, as well as the effectiveness of the research, technology-development, and diffusion process by which research has impacts. This paper provides an overview of available approaches and methodologies for the evaluation of agricultural research programs from a program evaluation perspective. Implications for future directions in the evaluation of agricultural research are suggested by comparing this overview with the methods used to evaluate returns to agricultural research described by Norton and Davis {10}.

Important opportunities exist for the development and use of methodologies to improve the utilization of evaluation findings in the decisionmaking process, to involve a broader set of stakeholders in the evaluation process, to consider more comprehensive economic, social, environmental and distributional impacts, and to address the problem of evaluation bias. The potential for incorporating methodologies and techniques used in the evaluation of other program areas and to engage evaluators from a number of disciplines, within and out of the agriculture community, is especially promising. The current evaluation techniques and evaluation expertise in agricultural research are strongly oriented itative and quantitative data collection and analysis techniques to the evaluation of the process and impacts of agricultural research programs.

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EXTERNALITY, EFFICIENCY, AND EQUITY RELATED TO AGRICULTURAL RESEARCH EXPENDITURES

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Introduction

Research aimed at increasing agricultural productivity is provided by both private and public sectors. While the private sector's contribution to agricultural research is significant, provision of these activities solely by the private sector would not be optimal because of the existence of various types of market failure.[1] Externalities or spillovers, which are commonly cited as a major form of market failure, clearly are evident with some types of agricultural research. Private firms would be able to capture only a portion of the benefits resulting from such research activities. It is well known that private markets may produce inefficient output levels in the face of these externalities. Government involvement in this area, therefore, may be necessary in order to correct for potential inefficiencies and inequities that would otherwise occur. However, the problems associated with externalities from agricultural research are not eliminated simply by having the government provide the service.

Benefits resulting from publicly provided research accrue not only to the producers in the state in which the research is conducted but also may spillover to producers in other states. This type of spillover from agricultural research expenditures has been recognized in a number of previous studies.[2] However, agricultural producers capture only part of the total benefits resulting from agricultural research activities. Consumers benefit as a result of expanded farm production and attendant lower prices.

Thus, benefits from efforts to increase agricultural productivity may accrue both within the state conducting the research and in other states, as well. The pervasive nature of agricultural research results affects the efficient allocation of resources and equitable financing of expenditures to improve productivity in agriculture.

The overall objective of this paper is to conceptually examine the impact of externalities associated with publicly provided production-oriented agricultural research activities. Policy implications resulting from externalities will be explored. Particular attention will be focused on the efficient allocation of agricultural research and its equitable financing while accounting for externalities.

Externalities Defined

Contributions related to the definition of externalities have been made by several authors including Meade (1952), Scitovsky (1954), Buchanan and Stubblebine (1962), and Whinston (1962). The proposed definitions concentrated on the element of interdependence--the economic welfare of one individual is dependent on the activities of another individual. Of course, the welfare of individuals is interdependent in an economic market. The distinguishing characteristic of an externality is that no conpensation is associated with this interdependence (Baumol, 1967, p. 25). Many economic actions initiated in the private sector create externalities, *i.e.*, exert external economic effects on producers and/or consumers which escape the price mechanism. An externality may be viewed as either an economic gain or loss not being reflected in the market price.

An analogous situation may occur in the public sector of the economy as the action of one unit of government can exert either beneficial or harmful effects on the residents of another governmental jurisdiction, without accompanying compensation.[3] Thus, agricultural research financed by one state may bring benefits to the residents of a nearby state (positive externality). For example, an improved crop variety developed in one state may be adopted in neighboring states to increase yields and hence total production. However, in some cases an action by a state may adversely affect residents of another state (negative externality). Producers in regions other than where the improved crop variety was developed and where that particular variety would not be suitable for adoption

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In general, public goods with significant externalities may be classified as either national or quasi-national public goods. A national public good, which is consumed equally by all residents (e.g. national defense), may be provided more efficiently by the federal government than by lower-level governments. Quasi-national public goods, on the other hand, are consumed on a less comprehensive basis throughout the nation. The mere existence of externalities associated with these public goods does not necessarily mean that they should be provided solely by the federal government since a highly centralized structure allows little opportunity for differences in expenditure patterns. Also, the federal government will not neccesarily be more efficient than lower-level governments in providing quasi-national public goods. However, the existence of significant externalities suggests a possible need for intergovernmental fiscal coordination.

Agricultural research serves as a good example of a quasi-national public good. Financing agricultural research at the state level produces benefits that are consumed by the state's residents, but in addition some benefits pass to other jurisdictions in the form of externalities. While it can be produced at either the federal or state level of government, the presence of externalities indicates a possible need for the coordination of the supply of agricultural research among various states in order to prevent an undersupply.

The principal source of agricultural research externalities is evident: state boundaries are historically given and do not coincide with benefit limits as represented by agricultural production regions. Agricultural research projects in one state which are designed with specific local problems in mind will likely produce results that can be directly applied in neighboring states within the same production region. Even applied research focused on a specific local problem may be adapted for more general purposes so as to meet the needs of producers in other regions. Furthermore, basic research is disseminated without regard to geographic boundaries.

Externality Impacts on Efficiency

A major problem related to the financing of agricultural research is to determine the efficient level of expenditures for a particular commodity. Institutional arrangements affect the approach to be used in determining efficient financing of agricultural research expenditures. The aggregate level of funding that is available for a particular state's agricultural research program is determined by Congress and the state's legislature, with recommendations and approval particular research areas. Administrators within agricultural experiment stations then allocate available funds among research areas. The issues of efficient financing of agricultural research, therefore, will be discussed in terms of these institutional constraints. The following discussion focuses on the implications of externalities on two major components: (1) determination of the aggregate level of expenditures for a particular state's agricultural research program, and (2) determination of efficient allocation of available funds among research areas. Determination of the federal government's equitable share of these expenditures, which can be used to correct for externalities, will be discussed in a later section.

An Efficient Aggregate Level of Expenditures

The process of determining the level of agricultural research expenditures may involve many issues affecting development and use of agricultural resources. However, this paper addresses economic criteria for determining the allocation of public funds among competing uses. To develop these criteria, assume that a principal goal of society is economic efficiency.

To simplify the argument assume that two states, A and B, experience an interdependency of agricultural research results. Each state has an agricultural activity that is dependent on the levels of research activity a and b in the two states, respectively. This relationship represents an externality which is not accounted for in the market because state A does not pay for the research results generated in state B even though they are used by producers in state A. It is possible, however, to measure the contribution of state B's research to output in state A and vice versa. The two production functions are given by $Y^A(a,b)$ and $Y^B(a,b)$. Aggregate net benefits from production generated by research activities can be measured by

$$(1)\quad Z = P[Y^A(a,b) + Y^B(a,b)] - W_a a - W_b b$$

where

Z is aggregate net benefits from production,

P is price of output,

W_a and W_b are costs per unit of research in states A and B, respectively, and

a and b are research activity levels in states A and B, respectively.

Assuming a constant price in the product market, the first-order conditions for a maximum are:4/

$$(2)\quad \frac{\partial Z}{\partial a} = \frac{\partial Y^A}{\partial a} + P\,\frac{\partial Y^B}{\partial a} - W_a = 0$$

$$(3)\quad \frac{\partial Z}{\partial b} = P\,\frac{\partial Y^A}{\partial b} + P\,\frac{\partial Y^B}{\partial b} - W_b = 0$$

value of marginal product is equal to the per unit cost of research activity.

With this formulation, two problems may result from the presence of externalities. First, the externalities may lead to a local maximum due to failure of the second-order conditions. With sufficiently large positive values of cross externality terms $\partial^2 Y^A/\partial a \partial b$ and $\partial^2 Y^B/\partial a \partial b$, the condition that the Hessian determinant H is positive would be violated. As the level of research activity in state A is increased, its marginal productivity may fall off, other factors equal. However, an increase in research in state A increases the marginal productivity of state B's research activity. Hence, the mere presence of externalities complicates the decision-making process whereby the efficient level of research activities is determined.

There is another problem that would result in some of the critical social benefits being ignored. This problem arises when the level of research activity is determined on the basis of a state's perspective rather than society's perspective. From the relationships in equations (2) and (3) it is clear that the efficient level of research activities from society's perspective involves internal benefits for the state as well as spillovers to other states. In selecting the appropriate level of research activity, policymakers in state A will stress those benefits which accrue to the state, $\partial Y^A\ \partial a$, and ignore those spilling over to other states, $\partial Y^B/\partial a$. With positive net spillovers, the level of research expenditures is likely to be too small relative to the interests of society as a whole if the activity is financed solely at the state level.

Efficient Allocation Among Research Areas

At the experiment station level, an efficient allocation of funds can be achieved by maximizing the value of output which can be produced given certain constraints. The amount of aggregate expenditures is limited and the production function is fixed. The case of two commodities and two states A and B will be examined. However, only the decision-making process in state A will be considered, with allowances for externalities associated with state B. The solution to this problem can be obtained using the method of Lagrange multipliers

$$(4)\quad U^A = P_1 Y^{A1}(a_1,b_1) + P_2 Y^{A2}(a_2,b_2) + P_1 Y^{B1}(a_1,b_1) + P_2 Y^{B2}(a_2,b_2) + \lambda(B^0 - W_1 a_1 - W_2 a_2)$$

where

P_i is the price of the ith commodity,

Y^{Ai} and Y^{Bi} are production functions for ith commodity in states A and B, respectively,

a_i is level of research activity for ith commodity in state A,

b_i is level of research activity for ith commodity in state B and is assumed to be fixed,

B^0 is budget constraint for state A,

W_i is per unit cost of research activity for ith commodity, and

λ is the Lagrange multiplier.

The term to be maximized represents total value of output to society in both states A and B for variable levels of research activity in state A but fixed levels of research activity in state B.

A necessary condition for maximum economic efficiency is achieved by allocating expenditures among the different research areas in such a manner that the ratios of value of marginal products to per unit costs are equal. While there are not likely to be major disagreements over this general concept, special consideration needs to be given to determine which variables should be used in calculating the value of marginal products. There are two alternatives that policymakers might consider.

The first alternative, which is socially optimum, takes into consideration internal benefits and benefits generated by the state under consideration but which spillover to other states. From the first-order conditions

$$(5)\quad \lambda = \frac{P_1\frac{\partial Y^{A1}}{\partial a_1} + P_1\frac{\partial Y^{B1}}{\partial a_1}}{W_1} = \frac{P_2\frac{\partial Y^{A2}}{\partial a_2} + P_2\frac{\partial Y^{B2}}{\partial a_2}}{W_2}$$

In this situation, it is evident that the marginal productivity of research in state A is a function of its research that creates benefits accruing to state A and research in state B that spills over to state A, as well as research benefits created in state A but spilling over to state B.

The second alternative involves finding the efficient allocation of research expenditures when only internal benefits are considered. This alternative, which is characteristic of a state operating in its own best interest, involves internal benefits generated from local

$$(6)\quad \lambda = \frac{P_1 \frac{\partial Y^{A1}}{\partial a_1}}{W_1} = \frac{P_2 \frac{\partial Y^{A2}}{\partial a_2}}{W_2}$$

The contribution to total value of output of the last dollar expended upon each research activity must equal λ. These measures of productivity include only the benefits accruing to the state conducting the research, while ignoring social benefits generated by its research that accrue to other states. Since the production function for state A is a function of research activity levels a and b, the marginal product with respect to research activity a may be a function of research activity b. Hence, the productivity of research may be a function of spillins from other states. This concept implies that when research funds are allocated within a state recognition should be given to the level of research activities in neighboring states, even if the state proposes to ignore spillovers from its own research activities.

How will changes in research activities in other states affect the efficient allocation of research expenditures in a particular state? First, some research activities in other states can be considered as substitutes for research activities in the state under consideration, state i. The extreme case of perfect substitutes would be duplication of effort, but to a lesser extent similar research on a given topic by researchers in two states might prove to be close substitutes for one another. In the case of substitutes, the efficient level of research expenditures in state i on commodity h should be reduced as other states increase their expenditures on that commodity, especially if economies of scale exist. This approach indicates the possibility of specialization in some states. Secondly, research conducted in other states could be complementary to research in the ith state. In this case, expanded research in neighboring states would increase the marginal productivity of research in the ith state and thus call for increased research expenditures in the ith state.

Another factor to be taken into account is the relative importance of the commodity under consideration. The presence of externalities in the form of spillins from complementary research results in an efficient allocation of research that differs from the relative importance of the commodity (Garren and White). First, consider the case in which the state acts in its own best interest and ignores spillovers to other states, with efficient allocation criteria as specified in equation (6). When commodity h is relatively less important in the state under consideration than in other states which generate the spillins, a smaller portion of research expenditures should production. However, when commodity h is relatively more important in the state under consideration than in other states, a larger proportion of total research funds should be allocated to that commodity than called for by its relative importance in the state's total production.

The second case is socially optimum since the calculation of the marginal product of research includes not only benefits to the state conducting the research but also benefits to other states. In this situation the marginal product of research as specified in equation (5) would be equated among commodity areas. Consider a situation in which the relative importance of commodity h in state i is less than in other states which receive spillover benefits from state i. Socially optimum allocation of funds in this case requires that a greater proportion of funds be allocated to the commodity than dictated by its relative importance in the state's total production. On the other hand, a smaller share of funds than dictated by its relative importance would be allocated to a commodity when its relative importance in state i is greater than in other states receiving spillover from that state.

Expenditure Allocation With Risk

The preceding discussions examined the process of efficient allocation of expenditures under conditions of certainty. Allocation decisions were based solely upon measures of marginal productivity of research activities. Policymakers may also consider the risk components associated with the benefits resulting from research expenditures. Risk can be defined in terms of the variability that is likely to occur in future returns.

When there are differences in risks among research areas, relatively less funds might be allocated to areas with higher risks. This criterion would give higher returns on riskier investments, with part of the higher return being a risk premium. Yet, this type of allocation would be inefficient, because the riskiness of returns on investment does not detract from their contribution to real national income (U.S. Congress, 1968). Satisfaction derived from the national output is independent of risk taken on the nation's investment, particularly public investment.

The risks on investments to society as a whole are far smaller than the sum of risks of individual investments. When the benefits from research in one state fall short of their expected level, other research activities may succeed beyond expectations. However, this does not mean that policymakers in a given state will ignore the concept of riskiness of research activities.

relationship to other existing research activities. The presence of externalities would dictate that the risk relationships among states be explored. A theoretical framework for measuring return and risk for combinations of research activities could be developed along the lines of portfolio analysis. The purpose of considering portfolios of risky research activities is to attempt to diversify away risk by selecting a combination of research activities that will minimize the level of risk for a given level of value of output. Variability associated with benefits from research activities in state A can be expressed as

$$(7)\quad V^A = \sum_{i=1}^{n} \sum_{j=2}^{n} a_i a_j \operatorname{cov}(a_i a_j) + \sum_{i=1}^{n} \sum_{j=1}^{n} a_i b_j \operatorname{cov}(a_i b_j)$$

where

V^A is total variance of research benefits,

cov(i,j) is covariance of benefits from ith and jth research activities or variance if i=j.

a is the level of research activities in state A, and

b is the level of research activities in state B.

The marginal contribution of a particular research activity a_i to overall variability can be measured by the partial derivative of variance (V^A) with respect to a_i.

$$(8)\quad \frac{\partial V^A}{\partial a_i} = 2 \sum_{j=1}^{n} a_j \operatorname{cov}(a_i a_j) + 2 \sum_{j=1}^{n} b_j \operatorname{cov}(a_i b_j)$$

The change in overall variance resulting from a one unit change in the ith research activity is dependent on its covariance with other research activities in state A, as well as research activities in state B. This relationship reflects variance from society's perspective. However, the state operating in its own best interest will ignore the later terms associated with externalities. If the sum of the covariance terms with state B's research in equation (8) had been negative then risk to society is reduced by increasing the level of research activity a_i. On the other hand, a positive sum indicates a need to reduce the level of a_i in order to reduce overall variance of returns.

If the level of research activity in each state is based on benefits to the state rather than on benefits to society as a whole, potential inefficiencies arise. Externalities must be accounted for and internalized if research activity levels are to be efficiently determined. However, there is no self-correcting mechanism to insure efficient levels of agricultural research. In this section a discussion of possible corrective actions for externalities is presented.

The mere existence of an externality does not in itself merit corrective action. It may be that a greater loss in welfare will occur from internalizing an externality through a resource reallocation than the gain in welfare deriving from such an action (Coase, 1960). For example, the cost of internalizing a positive externality, where social benefits exceed internal benefits to a particular state, may be greater than the total benefits of the externality itself. On the other hand, the cost of internalizing an externality through a resource reallocation, in many cases, may warrant a policy adjustment. This would be true if the cost of internalization is less than the total benefits deriving from such an action. An explicit consideration of benefits and costs is needed to justify such an action. Therefore, estimation of the magnitude of agricultural research externalities and the cost of internalizing these externalities is required in order to justify policy adjustments relating to these externalities.

Voluntary Action Among States

Spillover benefits generated by state A which accrue to the residents of state B generally are not accounted for by state A policymakers. The earlier argument concerning neglect of these externalities has been that state A will provide a smaller level of research expenditures than would be efficient from society's perspective. Given the possibility of negotiation between states, state B may find it advantageous to pay A to increase its level of research activities. Such a subsidy will reduce A's research costs thus leading to a higher level of research activities. The negotiation process will likely be complicated by the fact that spillovers flow in both directions between the two states. Furthermore, the outcome will depend on the relative bargaining strength of the two states and will not necessarily lead to an efficient solution to the externality problem (Musgrave and Musgrave, 1973).

In those cases in which only a small number of decision-making units are involved, voluntary action among the interested parties could be used in such a manner that all benefits are considered (Oates, 1972, pp. 67-68). For example, if only commodity with the research effort supported by the other states. However, attempting to coordinate these activities involves decision-making costs which include the value of time, effort, and direct outlays related to the bargaining process. These costs increase rapidly with the number of decision-making units involved as a result of having to obtain agreement among more parties (Buchanan and Tullock). For those cases in which externalities from agricultural research affect a large number of decision-making units, total decision-making costs of effective coordinated action are likely to be quite large. When the impact on consumers is considered then a large number of states would be concerned with almost all aspects of agricultural research.

Federal Government Action

One feasible solution to correct for externalities when a large number of states is involved is partial funding by the federal government. The federal government can grant funds to the state to induce it to raise the level of agricultural research expenditures. The principal technique used to increase state expenditures for other governmental services which create externalities is the matching grant, where according to a specified formula the recipient government is required to match the granted funds with funds from its own sources. While some federal grants for agricultural research require matching funds, the federal government does not presently match every state dollar with a specified amount of support. However, the matching grant program can serve as a standard of evaluation for the current system of federal grants for agricultural research.

With the matching grant, the formula for matching funding is based on the relative importance of external and internal benefits. If these grant programs are properly designed, they should direct state expenditures toward levels considered optimal from a societal perspective rather than a state perspective by financing the cost of external benefits or internalizing the externalities. The ratio of spillovers to internal benefits could be used to determine the federal government's share of research expenditures. Obviously, the development of an appropriate matching grant program requires identification and quantification of state benefits and spillovers from agricultural research expenditures.

Measurement of Externalities

In order to quantify the externalities associated with agricultural research, it must be assumed that research is a productive activity and that it is possible to accurately measure differences in this activity among states. The real value of agricultural research expenditures has widely been used for this purpose, but it is used in identifying differences in research activity.

Externalities associated with research can be measured through either production functions or supply relationships. While the effects of internal research activities on these relationships have been examined in previous studies, the impact of research activities in other states has been largely ignored. However, externalities can be accounted for by examining the role of spillin benefits from agricultural research. Spillins are the benefits accruing to a state as a result of research being conducted outside the state. The contribution of research to agricultural production can be estimated by fitting a production function that includes separate variables for research in the state and research in other states that are expected to affect the production in the state under consideration. When specified as a lag relationship, the production function is:

$$(9) \quad Q_{hit} = f(X_{hjit}, R_{hit-m}, R_{hkt-m})$$

where

Q_{hit} = quantity of commodity h produced in state i in time period t,

X_{hjit} = jth conventional input used in state i in time period t in production of commodity h,

R_{hit-m} = agricultural research activities in state i and time period t-m on commodity h, and

R_{hkt-m} = agricultural research activities in state k and time period t-m on commodity h with $i \neq k$.

Conclusions

The allocational efficiency implications of externalities related to agricultural research have been examined conceptually in this paper. A major obstacle to efficient allocation of agricultural research activities in the past has been a lack of information on externalities associated with these activities. However, there is increasing evidence that research interest is being focused on empirically estimating the magnitude of spillover benefits from agricultural research. Even though available information is still incomplete, it is useful to consider what the efficient solution would be if the necessary information was available. The issues raised in this paper may be useful both to those who are applying quantitative techniques to the area of research evaluation at the sub-national level and to those who are studying public policies and institutions providing agricultural research basis on which to determine the optimum level of research activities. Instead, these allocational efficiency concepts may be used to evaluate the consequences of selected allocation decisions or used in conjunction with other decision-making criteria. While economists tranditionally place major emphasis on the efficient allocation of resources, it is recognized that other criteria such as equitable income distribution are also important. Changes in the allocation of agricultural research activities in order to correct for externalities may have significant distributional effects.

In conclusion, the presence of externalities resulting from agricultural research creates a necessary, but not in all cases a sufficient, condition for the implementation of a policy aimed at internalizing the benefits. Producers as well as consumers throughout the country have vested interests in agricultural research, indicating the voluntary action designed for small groups would be an inappropriate solution to potential inefficiencies caused by externalities. Hence, intergovernmental transfers exist as one of the major tools to improve resource allocation and societal welfare.

Footnotes

1/Sources of market failure include external benefits and growth-inducing spillovers that are not appropriable by private firms.

2/A pioneering work related to diffusion of technology was Griliches' (1957) study of the geographical distribution of research results related to hybrid corn. Several other studies that examined the interregional diffusion of certain technologies are reviewed in Peterson and Hayami (1977).

3/This concept in the public sector may be referred to as that of intergovernmental externality.

4/Dropping the assumption of a constant price in the product market, would result in first-order conditions as follows:

$$\frac{\partial Z}{\partial a} = P \left[1 + \frac{1}{\eta} \frac{Y^A}{Y^T}\right] \left[\frac{\partial Y^A}{\partial a} + \frac{\partial Y^B}{\partial a}\right] - W_a = 0$$

$$\frac{\partial Z}{\partial b} = P \left[1 + \frac{1}{\eta} \frac{Y^B}{Y^T}\right] \left[\frac{\partial Y^A}{\partial b} + \frac{\partial Y^B}{\partial b}\right] - W_b = 0$$

where is the price elasticity of demand and Y^T is total output for the nation. The greater the elasticity of demand, ceteris paribus, the greater the marginal product of research from producer's perspectives.

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INTERREGIONAL SPILLOVER OF AGRICULTURAL RESEARCH RESULTS AND INTERGOVERNMENTAL FINANCE:

SOME PRELIMINARY RESULTS

Fred C. White and Joseph Havlicek, Jr.*

Introduction

Agricultural research, as with many other governmental services, can be performed efficiently at the state level but produces benefits that accrue to a broader area than just the originating state or region. Results from basic research, for example, would be unrestricted by geographic boundaries. Even applied research which is designed to solve specific problems encountered in a particular state may result in spillovers--geographically external benefits--to other areas. For example, some research results can readily be applied over wide geographic areas while other results need only additional adaptive research before they are suitable for other areas.

The idea that the benefits of agricultural research are not realized solely by the state or region providing the research expenditures is not a new one. Several researchers have analyzed the interregional diffusion of a particular technology (Peterson and Hayami, 1977, pp. 524-526). In the study of hybrid corn diffusion, Griliches (1957) found that differences among regions in adoption rates were dependent on such factors as the size and density of commodity production and profitability of the new technology. Despite the widespread concern over the diffusion of a particular technology, the external benefits of agricultural research have not received much attention from economists working in the general area of research evaluation and planning.

Attempts at measuring the contribution of agricultural research to agricultural production have often utilized a production function for a commodity or agricultural sector as a whole in such a manner that research was included as a separate variable (Peterson and Hayami, 1977, pp. 520-521). The majority of studies which have included research as a separate variable in a production function have been aimed at the national level rather than the regional or state levels. Griliches' (1964) work was one of the first publications in the area and Evenson's (1967) work was really important because it revealed the nature of the lag between the research input and increased output. The production function approach provides an estimate of the marginal product of agricultural research which is particularly useful in guiding decisions about allocation of resources to agricultural research.

Studies directed at the state or regional level confront a major problem not encountered in a national analysis: interregional spillovers of the benefits from agricultural research results. This problem has been termed pervasiveness, indicating the tendency for research results generated in one region to be incorporated into farm production functions in other regions (Evenson, 1971, p. 173). Latimer and Paarlberg (1965) and Evenson (1971) recognized the pervasiveness problem. Latimer and Paarlberg were unable to find a statistically significant relationship between research expenditures within the state and agricultural output. They attributed these findings to the pervasive nature of agricultural research results (Latimer and Paarlberg, p. 239). Evenson included a variable which measured the intensity of commodity research in an attempt to control for the pervasiveness of research (1971, p. 177). If research results were completely pervasive, Evenson argued, this variable would dominate the state research variable. The variable was statistically significant indicating that the interregional transfer of agricultural research results should be taken into account in cross-sectional analyses.

The existence of spillover benefits has a bearing on the allocation of research funds both within and between states. One important problem is to determine the appropriate balance between federal and state government in financing agricultural research. More specifically, what portion of the research expenditures should be financed by the federal government? The federal government initially served as a catalyst

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tural Experiment Station Act of 1887 reflect the emergence of a dual federal-state approach to agricultural research (Peterson and Fitzharris, 1977, pp. 72-73). Under these acts, each state received funds for a college of agricultural and mechanical arts and for an agricultural experiment station. This institutional framework is still a dominant force in agricultural research. Federal funds are allocated by a formula which is based largely on a state's rural and farm population (Peterson and Hayami, 1977, p. 522). Assuming that this system of finance was appropriate when it was first devised, is it still equitable after almost a century?

This paper deals with the effects of spillovers of agricultural research benefits on the financing of research by federal and state governments. It considers conceptual problems of financing government services which produce spillovers and proposes a model to align a region's investment in agricultural research with social benefits by compensating for spillovers with funds from the federal government. Interregional spillovers of the benefits from agricultural research results are empirically measured in order to determine the appropriate balance between federal and state funding of agricultural research.

Conceptual Framework for Financing Externalities

The purpose of this section is to investigate the nature of the divergence between regional and social benefits from agricultural research and the ways in which the federal government can make them coincide. Particular attention will be focused on the rationale for intergovernmental grants from the federal government to finance agricultural research.

A production externality occurs whenever results from agricultural research investments in one region affect agricultural production in other regions.1/ This phenomenon of interdependence in production can be analyzed through the basic model of joint production. Consider the case in which a production possibility schedule for agricultural output in region i is assumed to be related to the quantity of conventional inputs employed in region i, as well as research expenditures within region i and in other regions. The problem is further complicated by the fact that research expenditures over several years may affect agricultural output. The appropriate model of joint production is given by:

$$(1) \quad F(Q_{1t},---,Q_{nt}, X_{11t},---,X_{mnt},R_{1t},---R_{1t-w}, ---R_{nt-W}) = 0$$

and time period t,

X_{ijt} is the jth conventional input in region i and time period t,

$R_{i(t-w)}$ is agricultural research expenditures in region i and time period t-w.

$i=1,2,---n$ is the number of regions,

$j=1,2,---m$ is the number of conventional inputs,

$t=1,2,---T$ is the number of time periods and,

$w=0,1,2,---W$ is the number of lagged time periods over which agricultural research affects the output of the current time period.

This implicit function, which defines the set of inputs and outputs that may be feasibly attained is subject to the following conditions related to any regions i and k.

$$\frac{\partial Q_{it}}{\partial R_{k(t-w)}} \geq 0 \text{ for } w=0,1,2,---W$$

$$\frac{\partial Q_{it}}{\partial X_{kjt}} = 0 \text{ for } i \neq k$$

These conditions state that research in one region may affect output in other regions but conventional input usage in one region has no effect on output in any other region.

The existence of externalities complicates the dual problems of optimal provision and financing of agricultural research. First, consider society's problem in finding the optimum amount of research expenditures subject to the production constraint. One such procedure is to increase research expenditures up to the point where its internal rate of return is just equal to returns from alternative social investments (r_i).

$$(2) \quad \sum_{w=0}^{W} \frac{P_{it}MP_{i(t-w)}}{(1+r_i)^w} -1 = 0$$

where

P_{it} is the price of the output in region i and time period t,

$MP_{i(t-w)}$ is the marginal product of research in region i and time period t-w, and

r_i is the rate of return in region i for the best alternative social investments.

marginal benefits discounted at the social rate of return is just equal to its marginal cost. Thus, on the margin each dollar of expenditures will generate benefits equal to one dollar in present value.

The partial derivative of the production function with respect to research in the ith region is:

$$(3) \quad MP_{i(t-w)} = \frac{\partial Q_{it}}{\partial Ri(t-w)} + \sum_{k \neq i} \frac{\partial Q_{kt}}{\partial R_{i(t-w)}} \quad \text{for}$$

$$w=0,1,2,---,W$$

This expression indicates that the marginal benefits of region i can be separated into two components, benefits accruing to region i and benefits accruing to other regions. In selecting the appropriate level of research expenditures, policy makers in region i will stress those benefits which accrue to the region and ignore those spilling over to other regions. With positive net spillovers, the level of research expenditures is likely to be too small relative to the interests of the country as a whole if the activity is financed at the regional level. This situation is depicted in Figure 1 by the region's selection of R_1 as the appropriate level of research expenditures with the choice based on equating marginal efficiency of research investment from the regional perspective (mer_i) with the social rate of return (r). This decisionmaking process ignores the marginal efficiency of research investment from the national perspective (mer_N), which indicates that the socially optimum level of research expenditures is R_2. The externality problem raises the issues of society's optimal financing of agricultural research.

If the level of expenditures in each region was based on benefits to the nation as a whole rather than the benefits to the region, the potential inefficiency would be resolved. In those cases in which only a small number of decisionmaking units are involved, voluntary action among the interested parties could be used in such a manner that all benefits are considered (Oates, pp. 67-68). However, attempting to coordinate these activities involves costs which increase rapidly as larger numbers of parties are involved. Externalities from agricultural research affect a large number of decisionmaking units, and therefore the costs and the difficulties of effective coordinated action is expected to be quite large. One feasible solution, short of transfering the research activity to the federal government, is for the federal government to grant funds to the state to induce it to raise the level of agricultural research.

vices which create externalities is the matching grant, where according to a specified formula the recipient government is required to match the granted funds with funds from its own sources. While some federal grants for agricultural research require matching funds, the federal government does not presently match every state dollar with a specified amount of support. However, the matching grant program can serve as a standard of evaluation for the current system of federal grants for agricultural research.

With the matching grant, the formula for matching funding is based on the relative importance of external and internal benefits. If these grant programs are properly designed, they should direct regional expenditures toward optimum levels by financing the cost of external benefits or internalizing the externalities. This procedure can best be understood by referring to Figure 1. The socially optimum level of research expenditures is R_2 found at the intersection of r, the social rate of return, and mer_N, the marginal efficiency of research investment from the national perspective. Since the region's decision on research funding is based on mer_i, the matching grant program from the federal government should reduce the region's effective cost to r'. The region will therefore choose R_2 as the appropriate level of research expenditures by equating marginal regional benefits (mer_i) with marginal regional costs (r'). The matching formula in this case will be $(r - r')/r'$ as the appropriate balance between federal and regional funding of agricultural research.

The development of an appropriate matching grant program requires identification and quantification of regional benefits and spillovers from agricultural research. The traditional prescription to compensate for externalities, as proposed by A. C. Pigou (1932), is to provide a unit subsidy equal to the value at the margin of the spillovers. This concept is used in the present analysis to measure regional benefits and spillovers. Benefits from agricultural research expenditures in a given region from the regional point of view are measured by the contribution of the expenditures to output within the region:

$$(4) \quad B_{it} = P_{it} \left[\sum_{w=0}^{W} \frac{\partial Q_{it}}{\partial R_{i(t-w)}} R_{i(t-w)} \right]$$

time period t from agricultural research expenditures in region i during the w=0, 1,2,---,W previous time periods.

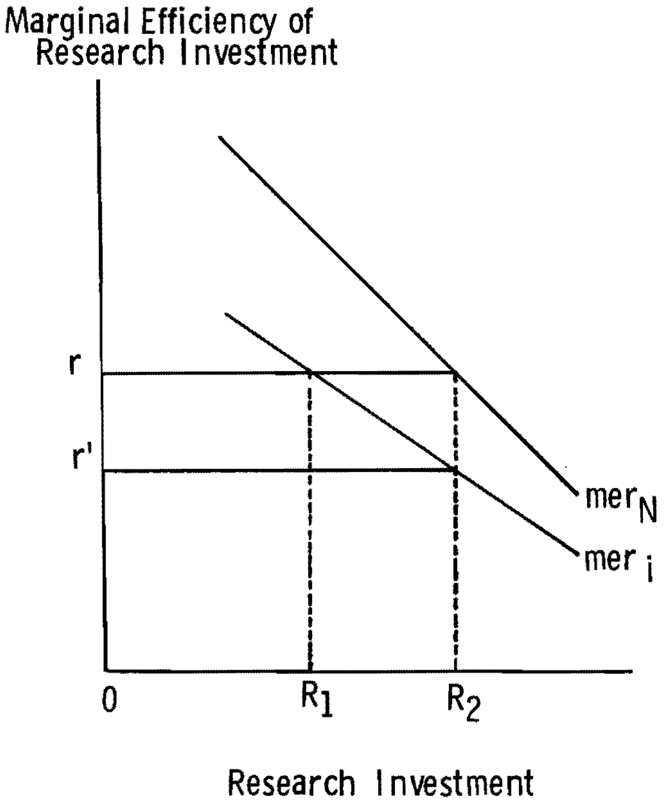
Valuing benefits by this criterion is equivalent to paying resouces according to their marginal productivities. Similarly, spillovers of agricultural research conducted in region i are measured by the contribution of the expenditures to output in all other regions:

$$(5)\quad S_{it} = \sum_{k\neq i} P_{kt}\left[\sum_{w=0}^{W}\frac{\partial Q_{kt}}{\partial R_{i(t-w)}}\cdot R_{i(t-w)}\right]$$

where

S_{it} is the value of spillover benefits in time period t from agricultural research expenditures in region i during the w=0,1,2,--- W previous time periods.

Figure 1. Adjustment for External Benefits



sum of the benefits to the originating region, B_{it} and spillovers, S_{it}. The relative importance of spillovers to regional benefits in time period t is measured by:

$$(6)\quad M_{it} = \frac{S_{it}}{B_{it}}$$

where

M_{it} is the ratio of spillovers to regional benefits in time period t.

In developing a federal grants program, M_{it} could be used as a guide in determining the federal government's share of research expenditures (Musgrave and Musgrave, 1976, p. 630).

The impact of federal grants on the level of research expenditures is dependent on the magnitude of the marginal revenue from grants. However, it is possible to draw some general conclusions relating to the suitability of federal grants for achieving particular objectives. First, a matching grant program for agricultural research would tend to increase the level of these expenditures by reducing the net price of agricultural research relative to other public and private goods. Secondly, the program would help correct for spillovers so that regional benefits would more closely coincide with social benefits.

The Model

In this study a production function which includes variables to reflect conventional inputs as well as agricultural research is estimated and is the basis for measuring the contribution of research to agricultural production. Various outputs are aggregated into a single variable by using relative price weights. Input variables are similarly aggregated and will thus abstract from quality differences that are not reflected in input prices. While this estimation procedure controls for the use of other inputs that are expected to influence agricultural output, we are particularly interested in the effect of agricultural research on productivity. The expected relationship between agricultural research and agricultural output is discussed in the following paragraphs.

Ideally, we would like to capture the spillovers of research results from region i to region k for every i and k. However, accounting for such a large number of interregional flows would be very difficult in a single regression equation. Furthermore, for purposes of this study it is only necessary to measure the for research expenditures inside the region and research expenditures outside the region. The spillovers in aggregate (or spillins) into the ith region in time period t are:

$$(7) \quad SI_{it} = \sum_{k \neq i} P_{it} \left[\sum_{w=0}^{W} \frac{\partial Q_{it}}{\partial R_{k(t-w)}} \cdot R_{k(t-w)} \right]$$

where

SI_{it} is the value of the spillover benefits into region i in time period t from agricultural research expenditures in the other (n-1) regions during the w=0,1,2, ---,W previous time periods.

The time path of output response to increased expenditures on research is particularly important in estimating the benefits from research. If the output response is not forthcoming in the same year the investment is made, then the estimated marginal product overstates the marginal returns from research investment. Evenson was perhaps the first to identify the nature of the lag between the research input and increased output. He found, that in response to increased expenditures on research, agricultural output first increased and then decreased, with the average length of lag between six and seven years. At the regional level this lagged relationship is assumed to exist for research expenditures both within the region and outside the region.

Extension investment within the region also affects agricultural output. However, measuring the influence of extension on agricultural productivity separate from research has been difficult. If extension's role is distinct from that of research, then a separate extension variable should be used in the production function. However, if extension's role can be viewed as improving labor quality, its effect on productivity can be considered similar to that of research. Consequently, it would be difficult to distinguish between the contribution of research and extension (Evenson, 1967, p. 1421). The latter case is assumed to be the appropriate situation in the present study. Therefore, research and extension expenditures within the region are combined into one variable. Extension is assumed to have no spillover effect to other regions.

The model used as the basis for empirical analysis is:

$$(8) \quad Q_{it} = \beta_0 \prod_{j=1}^{m} X_{ijt}^{\beta j} \prod_{w=0}^{W} RI_{i(t-w)}^{\beta_{m+w}} \prod_{v=0}^{V} RO_{i(t-v)}^{\beta_{m+W+v}}$$

X_{ijt} is the per acre value of the jth conventional input in region i and time period t,

$RI_{i(t-w)}$ is the research and extension expenditures per state inside region i for time period (t-w),

$RO_{i(t-v)}$ is the research expenditure per state outside region i for time period (t-v),

β's are regression coefficients,

i=1,2,---,n is the number of regions,

j=1,2,---,m is the number of conventional inputs,

t=1,2,---,T is the number of time periods,

w=0,1,2,---,W is the number of lagged time periods over which agricultural research and extension expenditures within a region affect agricultural output in region i during time period t, and,

v=0,1,2,---,V is the number of lagged time periods over which agricultural research expenditures outside of region i affect agricultural output in region i during time period t.

A production function such as the one presented above provides several sets of interrelated relationships that are important for economic decisions on resource use. Considering the unique aspects of the present analysis, attention will be focused on factor-product transformation ratios for research and extension inside the region and research outside the region.

Statistical Model and Data

The unit of analysis is an average state for each of the 10 agricultural production regions in the United States.2/ Estimates of the contribution of agricultural research to agricultural output are obtained from a production function which was estimated using data for the period 1949-1972. Data on research expenditures covered the period 1929-1972 to account for lagged effects of the research variables.

The statistical model is a cross-sectionally correlated and time-wise autoregressive double logarithmic production function with four conventional inputs and the research expenditures inside the region and outside of the region included as second order polynomial lags. The statistical production function is:

$$(9) \quad \ln Q_{it} = \ln \beta_0 + \beta_1 \ln X_{i1t} + \beta_2 \ln X_{i2t} + \beta_3 \ln X_{i3t} + \beta_4 \ln X_{i4t} + \beta_5 \ln RI_{it} + \beta_6 \ln RO_{it} + \varepsilon_{it}$$

$\ln Q_{it}$ is the natural logarithm of the value of agricultural output per acre in region i and time period t,

$\ln X_{i1t}$ is the natural logarithm of the per acre value of hired labor in region i and time period t,

$\ln X_{i2t}$ is the natural logarithm of the per acre value of feed and livestock in region i and time period t,

$\ln X_{i3t}$ is the natural logarithm of the per acre value of seed, fertilizer, lime and miscellaneous expenses in region i and time period t,

$\ln X_{i4t}$ is the natural logarithm of the per acre value of capital and depreciation in region i and time period t,

$\ln RI_{it}$ is the research and extension expenditure per state inside production region i pertaining to time period t measured as a second order polynomial in logarithms covering a 11-year lag and having both endpoints constrained to zero,

$\ln RO_{it}$ is the research expenditure per state outside region i pertaining to time period t measured as a second order polynomial in logarithms covering a 11-year lag and having both end points constrained to zero,

$\beta_0 . \beta_1, --- \beta_6$ are parameters and,

ε_{it} is the disturbance term associated with t^{th} observation in region i.

ε is assumed to be log normally distributed with the following behavioral attributes:

$$E(\varepsilon_{it}^2) = \sigma_{ii} \qquad \text{(heteroskedasticity)}$$

$$E(\varepsilon_{it}\ \varepsilon_{kt}) = \sigma_{ik} \qquad \text{(mutual correlation)}$$

$$\varepsilon_{it} = \rho_i\ \varepsilon_{i(t-1)} + U_{it} \quad \text{(autoregression)}$$

U_{it} is assumed to be log normally distributed and

$$E(\varepsilon_{i(t-1)}\ U_{kt}) = 0$$

$$E(U_{it}\ U_{kt}) = \phi_{ik} \qquad \text{(variance-covariance matrix after adjustment for serial correlation)}$$

$$E(U_{it}\ U_{ks}) = 0 \qquad (t \neq s),$$

for i,k=1,2,---,n and t=1,2,---,T.

mates a serial correlation coefficient for each region and adjustments for serial correlation are made in each region using the estimated regional serial correlation coefficient. After adjustment for serial correlation, the variance-covariance matrix for the agricultural production regions is estimated and the coefficients of the model are estimated relative to adjustments for heterogeneous variances and non-zero covariances among the regions.

Agricultural input and output data were obtained from Farm Income Estimates, 1949-1972 (U.S. Department of Agriculture). Agricultural output was the sum of farmer cash marketing, government payments to farmers, value of home consumption of farmers, and net farm inventory change. Four conventional input-expenditure categories were used: (1) hired labor, (2) feed and livestock, (3) seed, fertilizer, lime, and miscellaneous expenses, and (4) capital and depreciation. Agricultural output and all expenditures were recorded in million 1972 dollars.[3/]

Research and extension expenditures included only production-oriented expenditures. Data sources for these expenditures include Budget of the United States Government; Combined Statement of Receipts, Expenditures and Balances of the United States Government (U.S. Department of Treasury); Funds for Research at State Agricultural Experiment Stations and Other State Institutions (U.S. Department of Agriculture, Cooperative State Research Service); and Annual Report of Cooperative Extension Work in Agriculture (U.S. Department of Agriculture, Federal Extension Service). For a more detailed description of data sources see Cline (1975). Research and extension expenditures were also recorded in million 1972 dollars, with the personnel component of these expenditures deflated with an index of average salaries of college and university teachers (AAUP Bulletin) and the remaining expenditures deflated by the implicit price deflator for government purchases of goods and services.

Results

Empirical Production Function

The statistical results based on the data for the 10 production regions of the United States for the period 1949-1972 are presented in this section. Estimated regression coefficients and t-values are shown in Table 1. The sign of each coefficient on conventional inputs and education are consistent with *a priori* knowledge. Each of these coefficients is also different

Accounts for Interregional Spillovers of Agricultural Research Results.

Variable	Coefficient	Standard Error
Hired Labor	0.153122**	0.018093
Feed and Livestock	0.167828**	0.021168
Seed and Fertilizer	0.218450**	0.026108
Capital and Depreciation	0.467536**	0.023348
Year	Research and Extension Inside the Region	Research Outside the Region
t	0.000000	0.000000
t-1	0.003520	0.000000
t-2	0.006336	0.000000
t-3	0.008448	0.006130
t-4	0.009856	0.011034
t-5	0.010560	0.014712
t-6	0.010560	0.017164
t-7	0.009856	0.018390
t-8	0.008448	0.018390
t-9	0.006336	0.017164
t-10	0.003520	0.014712
t-11	0.000000	0.011034
t-12	0.000000	0.006130
t-13	0.000000	0.000000
Sum of Research and Extension Coefficients	0.077440**	0.134860**

**Statistically significant at the 0.01 level of significance.

from zero at the 0.01 level of significance. In particular, the elasticity of production is smallest for labor and highest for capital. It is also interesting to note that the sum of the coefficients on conventional inputs is approximately one, indicating constant returns to scale without the influence of research.

As indicated in equation (9) the model to be estimated in this study contained lags on research and extension expenditures within the region and research expenditures outside the region. In addition, research expenditures outside the region would probably not affect the regional output immediately, indicating a more complicated lagged structure associated with these expenditures. Second-degree polynomial expenditure lags[4/] which were considered appropriate for this study were chosen from a large number of regression equations using different time lags with the final choice being on minimum mean square error. Research and extension al output for 11 years. Research expenditures outside the region had no effect on regional output for the first two years and then affected regional output for 11 years. Combining these two separate effects from the regional analysis indicates that research and extension expenditures affect agricultural output over a 13-year period. These results are consistent with aggregate studies by Evenson (1967) and Cline (1975) which found a 13-year lag. However, the present analysis sheds further light on the nature of the lag, indicating the importance of interregional flows of research results.

The effect of these expenditures on output in each year is also shown in Table 1. Research and extension expenditures inside the region have the greatest impact on regional output in the fifth and sixth years, while research outside the region has the greatest impact in the seventh and eighth years. The sum of the regression coefficients on research and extension expenditures inside the region is 0.0695 indicating that a 1% increase in research and extension expenditures increases output in the region by 0.0695% over its lifetime. These results are similar to estimates reported in previous studies.

Marginal Product and Rate of Return

The marginal product and rate of return for agricultural research and extension investment can be calculated from the regression results. The regression coefficients on the research and extension expenditure variables are elasticities. However, these elasticities can be converted to marginal products by the following equation:

$$(10)\quad TMPR_i = \sum_{w=0}^{W} MPR_{i(t-w)} = \sum_{w=0}^{W} \beta_{(t-w)} (\bar{Q}_i/\overline{RI}_i)$$

where

$TMPR_i$ is the marginal product of research and extension expenditures for region i aggregated over the lifetime of the investment,

$MPR_{i(t-w)}$ is the marginal product of research and extension expenditures in i and year (t-w),

$\bar{Q}_i$ is the mean level of agricultural output per state in region i, and

$\overline{RI}_i$ is mean level of research and extension expenditures per state in region i; both means are based on the 24 year period 1949-1972.

The marginal products for research and extension expenditures for the 10 regions are presented in Table 2. These estimates reflect the contribution to regional output of research and extension.

Region	Marginal Product	Regional Rate of Return	Average Annual Regional Benefits	Average Annual Spillovers	Ratio of Spillovers to Regional Benefits	Ratio of Federal-State Expenditures
	(Dollars)	(Percent)	---(Million	Dollars)---		
Northeast	7.28	43.5	512.86	673.75	1.31	0.97
Lake States	4.99	32.5	241.17	658.74	2.73	1.10
Corn Belt	8.20	47.2	632.20	1,288.79	2.04	1.25
Northern Plains	12.27	61.7	536.39	753.59	1.40	1.63
Appalachian	10.30	55.1	610.85	726.62	1.19	1.60
Southeast	5.92	37.2	367.42	513.61	1.40	1.37
Delta	4.77	31.3	220.80	548.51	2.48	1.80
Southern Plains	4.78	31.4	215.51	604.48	2.80	2.10
Mountain	7.98	46.4	474.88	758.26	1.60	2.35
Pacific	5.13	33.3	370.22	698.33	1.89	0.90
Aggregate	6.51	40.0	4,182.29	7,224.27	1.73	1.38

The Northern Plains and Appalachian Regions have the highest marginal productivity, reflecting relatively low levels of research and extension investments. In contrast, the Lake States, Southern Plains, and Delta Regions have the lowest marginal productivity. The "average" marginal product, which was estimated using national averages for agricultural output and research and extension expenditures, was $6.51 indicating the total returns from $1 invested.

Since the returns are not forthcoming immediately, it is important to determine the rate of return associated with research and extension investments. The regional rate of return (r_i) can be calculated as follows:

$$(11) \quad \sum_{w=0}^{W} MPR_{i(t-w)}/(1+r_i)^w - 1 = 0$$

This procedure explicitly accounts for the lag structure. The regional rate of return for research and extension investments are reported in Table 2. The average regional rate of return is 40%, ranging from 31 to 62%. There is a direct relationship between marginal products and rate of return on investment, since the same lag structure is assumed to exist in every region.

The rates of return estimated in this study are in serious conflict with estimates made in earlier studies. Evenson (1971) reported returns that ranged from 30 to 180% for the same 10 regions. His average rate of return and average marginal product for research and extension investments were more than double the estimates reported in the present study. This discrepancy can be explained by the fact that Evenson did not account for the interregional transfer of research results. Furthermore, the rates of return presented in Table 2 are regional rates of return and not social rates of return which include spillovers of research results.

Evaluation of the rates of return reported in Table 2 indicate that investments in agricultural research and extension yield a high rate of return (from 31 to 62%) for the originating region. It would appear that the returns from this type of investment would compare favorably with alternative public investments in the region even without considering spillovers to other regions.

Intergovernmental Finance

Regional benefits and spillovers are compared to develop a mechanism for reallocating costs between the federal government and the region on the basis of benefits realized within each region. Empirical estimates of regional benefits can be calculated as follows:

$$(12) \quad B_i = \sum_{w=0}^{W} \beta_{(t-w)}(\bar{Q}_i/\overline{RI}_i)(\overline{RI}_i) = TMPR_i\ (\overline{RI}_i)$$

$\beta^{i}_{(t-w)}$ is the regression coefficient of research and extension expenditures in year (t-w),

$\overline{Q}_i$ is mean level of agricultural output per state in region i,

$\overline{RI}_i$ is mean level of research and extension expenditures per state in region i, and

$TMPR_i$ is marginal product of research expenditures in region i.

This condition states that regional benefits are the product of (a) the level of research and extension expenditures and (b) its value marginal product. Calculating regional spillovers, which is slightly more complicated, begins with the calculation of spill-ins (SI) for each region.

$$(13)\quad SI_i = \sum_{v=0}^{V} \beta_{(t-v)}\, (\overline{Q}_i/\overline{RO}_i)\, \overline{RO}_i = TMPRO_i\, (\overline{RO}_i)$$

where

SI_i is spill-ins of agricultural research benefits in region i,

$\beta_{(t-v)}$ is a regression coefficient on the variable research expenditures outside the region in year (t-v),

$\overline{Q}_i$ is mean level of agricultural output per state in region i,

$\overline{RO}_i$ is mean level of research expenditures outside region i, and

$TMPRO_i$ is marginal product of research expenditures outside of region i.

These spill-ins in region i are allocated among neighboring regions in proportion to total research expenditures, which provides an estimate of spillovers from region i to region k. The process of calculating spill-ins in every region and allocating to the originating regions is repeated until all spill-ins have been accounted for.

$$(14)\quad S_i = \sum_{k \neq i} SI_k\, (R_i / \sum_{1 \neq k} R_1)$$

where

S_i is the value of spillover benefits from agricultural research expenditures in region i,

R_i is the level of research expenditures in region i, and

R_1 is the level of research expenditures in all regions that generate spillovers into region k.

Empirical estimates of regional benefits and spillovers as defined by equations (12) and (14), respectively, are shown in Table 2. 5/ These figures are annual averages for the 1949-1972 period reported in 1972 dollars. Regional benefits are highest in the Corn Belt. Four regions annually in regional benefits. With regards to spillovers of agricultural research benefits, all 10 regions generated more then $500 million of spillovers annually. The Corn Belt annually generated over $1.25 billion of spillovers to lead all regions in the amount of spillovers.

The average ratio of spillovers to regional benefits is 1.73 (Table 2). The Northeast and the Appalachian Regions have the lowest ratio of spillovers to regional benefits. Four regions have spillover-to-regional benefit ratios higher than two to one: Lake States, Corn Belt, Delta and Southern Plains. These differences can be explained by two factors: (1) the ratio of agricultural output to research and extension expenditures and (2) the ratio of extension to research expenditures. Those regions with low levels of research and extension expenditures relative to agricultural output have high marginal products for research and extension expenditures. Extension is assumed to create only regional benefits and not spillovers; thus, those regions in which extension is relatively important would have lower ratios of spillovers to regional benefits.

The ratio of federal-to-state expenditures for agricultural research and extension, which are presented in Table 2, can be compared with the ratio of spillovers to regional benefits to determine whether the federal government actually financed the spillovers. These results indicate that the federal government financed all of the spillovers in only three regions, Northern Plains, Appalachian, and Mountain Regions. In aggregate, the ratio of federal-to-state expenditures is only 1.38 compared to 1.73 for the ratio of spillovers to regional benefits. Thus the federal government's contribution to production oriented agricultural research and extension expenditures would have to be increased 25% to align regional funding with regional benefits, on the average. However, several regions would require a greater increase in federal expenditures to yield an equitable distribution across all regions.

Implications

The ratio of spillovers to benefits for any region is not a constant but depends on the marginal productivity of research inside the region, as well as outside the region. A given unit subsidy would not ensure that the federal government would finance its appropriate share of agricultural research as determined by the relative importance of spillovers. Maintaining the proper balance between federal and state government finance would require a variable matching formula, one in which the shares of the federal government and the state governments varied with the level of research expenditures matter. While this study has shown that matching grants can provide a theoretical solution to the externalities problem, it is not the purpose of this study to propose a matching grant program for agricultural research. Instead, the intergovernmental grant program developed in this paper was presented as an analytical framework for evaluating the current system of federal support for agricultural research.

The limited scope of this analysis resulted in shortcomings that should be taken into consideration. First, the spillovers considered in this analysis were at the regional level rather than the state level. Benefits to the originating state would be less than regional benefits and conversely spillovers outside the state would be greater than spillovers outside the region. This study was focused at the regional level because previous research had indicated that it would be more likely to quantify systematic spillovers of agricultural research results among regions than among states. Results of this study demonstrate that interregional spillovers can be empirically measured. However, further research is needed.

Secondly, the production function estimated in this study can measure only average tendencies with respect to interregional spillovers. Thus, greater confidence can be placed on the aggregate estimates of regional benefits and spillovers than on the estimates for a particular region. Individual studies, region by region, would have to be undertaken in order to precisely measure the interregional flows of research benefits for a particular region. The authors have conducted such a study for the Southern Region, which includes four regions of the present study--Appalachian, Southeast, Delta, and Southern Plains. Results of that study indicated an internal rate of return of 20% for agricultural research and extension investment in the Southern Region. It is interesting to note that if the interregional spillovers had been ignored in formulating the model, the results would have incorrectly indicated a 72% rate of return on regional investment. These figures indicate the magnitude of the bias that results from failure to account for interregional spillovers of agricultural research results.

Conclusions

Interregional spillovers of agricultural research results create difficult problems related to the allocation and finance of research expenditures. As a result of these spillovers, regional benefits diverge from social benefits and therefore action by the federal government is needed to ensure that the level of research investment is optimum. form of intergovernmental grants which can be used to ensure that regional and social benefits coincide.

While the need for intergovernmental grants for agricultural research has been justified in this study primarily on the basis of interregional spillovers, the existence of spillovers is certainly not the only factor that should be taken into consideration in determining the federal government's support for agricultural research. Ideally, the returns from agricultural research investment will have to be compared with other investment alternatives. Thus interregional spillovers of agricultural research results is only one facet to be considered in determining the appropriate balance between federal and state governments in financing agricultural research. However, it is hoped that this study has contributed to the general understanding of agricultural research finance by identifying and quantifying interregional spillovers of agricultural research results.

Footnotes

1/For discussions of externalities see Buchanan and Stubblebine (1962), Davis and Whinston (1962), and Mishan (1971).

2/The 10 production regions correspond to a U.S. Department of Agriculture delineation as reported in such publications as Farm Real Estate Market Developments (U.S. Department of Agriculture).

3/Data source for price deflators was Agricultural Statustics (U.S. Department of Agriculture). Value of agricultural output was deflated with the index of prices received by farmers for all farm products. The labor input for agricultural hired labor was deflated by the index of prices paid for hired labor. Total expenditures for feed and livestock were deflated with the index of prices paid for feed and livestock, respectively. Total expenditures for seed, fertilizer, lime, and miscellaneous expenses were deflated with prices paid for seed, fertilizer, and all items in production, respectively. The capital and depreciation variable was the farm expenditures for repair and operation of capital items, and depreciation and other consumption of farm capital deflated by the index of prices paid for all items in production.

4/Previous research by Evenson (1967) and Cline (1975) indicated that a second-degree polynomial was most appropriate from both a theoretical and an empirical perspective.

equations (10) and (12) is that no price variable is explicitly considered in the latter two equations. The reason for this difference is that value rather than quantity is used as the dependent variable in the empirical estimation of the production function. Hence, the derivative of the production function with respect to research expenditures is value marginal product.

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SOME PRELIMINARY RESULTS OF ESTIMATING THE IMPACTS OF RESEARCH INVESTMENT ON CORN, WHEAT AND SORGHUM

Daniel Otto and Joseph Havlicek, Jr.*

Introduction

The aggregate approach to the evaluation of production oriented expenditure in the United States has consistently shown high rates of return to agricultural research investments. These efforts, while showing the value of agricultural research, are limited in the information they can provide policy and budget decisionmakers. More recently, efforts such as the analysis of four major commodity groups by Bredahl and Peterson and cross sectional studies by Evenson, White, and Havlicek have begun refining the level of analysis to individual regions and states and for specific commodities (Evenson, Bredahl and Peterson, White and Havlicek).

The objective of this study is to further disaggregate these commodity groupings of Bredahl and Peterson into individual commodities and to begin investigating the impact of interregional research "spillovers." Case studies of corn, wheat, and sorghum are made, using individual states as observation units over the time period for which research data on individual commodities are available. The empirical results presented in this paper are the results of some first attempts at estimation. Further work is being done to improve specification of variables measuring weather, cash inputs, risk, and other factors influencing yield response of grain commodities. A special cross sectional-time series algorithm is used in parameter estimation.

Theoretical Framework, Model, and Data

The conceptual framework of this study is particularly constrained by the availability of only 11 years of research expenditure data on individual commodities (1967-1977). The short number of years prohibits use of a 12-, to 13-year polynominal Almon distributed lag which has been used in previous studies to investigate the research lag structure (White, et al., Quance and Lu). The nonavailability of production input data for specific commodities for other than farm census years also limits utilizing the traditional aggregate production function approach to the analysis of agriculture research expenditure.

Faced with these data limitation problems, the framework of a supply response analysis is developed as an alternative to investigating the impact of research expenditures on productivity of individual grain commodities. The supply response model which is derivable from the production function, expresses the quantity of a commodity offered for sale as a function of input and output prices, technical parameters, and a variety of shifters, such as weather and technological change. Supply analysis studies have typically represented the effects of technological change as a linear trend variable. While the research evaluation studies have not focused on the processes of technological adoption and diffusion, their analyses have shown that public investments in agricultural research activities have contributed to increases in productivity. On this basis, lagged research expenditures on individual commodities will be used as the technological change shifter in the commodity response functions.

The Model

The general supply function for a particular commodity can be written as:

$$(1) \quad Q = f(PF, PQ, L)$$

where output (Q) is a function of price of the variable inputs (PF), price of the output (PQ) and the already decided land input (L). Under assumptions of profit maximizing behavior, which

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prices, the ratio of PF/PQ can also be used.

This specification of the supply function uses as its dependent variable, total output, which is based on yield per acre (Q/L) and total acreage components. The land, or acreage component of this function is typically used in supply response estimation and is influenced by economic, political, and environmental factors such as expected prices, government programs, and crop rotational requirements. The second component (Q/L) is affected by the level of fertilizer and other input used, along with the shifters such as weather and technological change. Since this second component better isolates the impact of technological change, via research investment, and is also a more precise measure of productivity change, this study will focus on explaining changes in yield per acre.

Estimating Equation and Data

The theoretical development of the previous section provides the basis for a more complete specification of factors influencing yields and the variables used in estimating yield response functions for corn, wheat, and sorghum. Data on these commodities were for the 1972-78 crop years with research expenditures lagged an additional four and five years to the beginning of that data series. The following is a general statement of the basic model actually used to estimate yield response equations for corn, wheat, and sorghum:

$$(2) \quad (Q/L) = g(PF, PQ, L, W, \Delta A, R, OR)$$

where (Q/L) is yield per acre of each commodity, (PF) is the price of fertilizer, (PQ) is the price of output, (L) is harvested acres, (W) is the weather variable, (ΔA) is the change in farm machinery assets, (R) is in-state research on a particular commodity, and (OR) is outside research on a particular commodity. A more detailed description of these variables is presented in Appendix Table A. The observations on these variables were drawn from a six-year time series for all commodities with cross sections of 23 states for sorghum, 36 states for wheat, and 39 states for the corn analysis.

Estimation Procedure

The cross section-time series nature of the data used in this study presents potential statistical problems to efficient parameter estimation. Within a pooled data sample, the nature of the disturbance between two states at some specific point in time may differ from the disturbance of a specific state over different been discussed and used by Balestra and Nerlove, Fuller and Battese, Parks and others (Kmenta). this study will be using the approach developed by Parks which combines the assumptions frequently made about cross sectional observations with those usually made concerning time series observations. Time series analysis often assumes that the disturbance terms are autoregressive, while cross sectional data frequently assumes that the disturbances are mutually independent and heteroskedastic. When the observational unit is a state which can cut across geoclimatic regions, the assumption of mutual independence may not be satisfied. The Parks model is a cross-sectionally correlated and time-wise autoregressive procedure useful in cases where the assumption of mutual independence is not made. This estimation procedure is used to estimate parameters of the models.1/

Empirical Results

Several variations of the general model in (2) were developed and tested using the Parks method of estimation from pooled cross sectional time series data. The usual summary statistics presented in Tables 1 and 2 differ from OLS results in several ways. By accounting for serial correlation, heteroskedasticity and non-zero covariances, individual parameter estimates have been made more efficient. Also, in terms of R^2 values, the Parks procedure, which is a GLS method, can do no better than the pooled OLS models which minimizes Sum of Squares Errors to obtain BLU Estimates. The R^2 values presented along with the results are from the pooled OLS estimates and can be interpreted as approximations of the explanatory power of these models. The yield models are all linear functions of prices and other variables.

Preliminary results for these models, estimated using the Parks method, are presented in Tables 1 and 2. Although the regression equations are significant, the results for the wheat and sorghum models indicate that a rather low proportion of the variation in yield per acre and absolute annual changes in yield were explained by the model. The combination of cross sectional and time series data exhibited large variations in yield levels ranging from 24 to 126 bushels per acre for corn, 13.2 to 75 bushels per acre for wheat, and 16 to 87 bushels per acre for sorghum. Attempts were made to deal with variations in yields due to possible classification of states through introduction of indicator variables for geographical regions and for states which are relatively small producers of these commodities (less than 100,000 acres). These classification efforts had mixed degrees of success. The dummy shifter for small producing states indicated higher levels of corn yields in

Table 1.

Results of Yield per Acre Functions for Wheat, Sorghum, and Corn Using Park's Method for Pooled Cross-Sectional and Time Ser
Data

	Con- stant	$\frac{PF_{t-1}}{PO_{t-1}}$	PF_{t-1}	PO_{t-1}	Sept. Weather	Har. Acres	Weighted Land	Irr. Acres	Change in M. Assets	Res.	O.S. Res.	D1	D1* O.S. Res.
Wheat 36 states	52.71 (3.19)		-.092 (1.88)	.766 (.712)	.055 (1.21)	-.0036 (7.04)		.619 (1.56)	.0021 (.503)	.032 (6.36)	-.0061 (1.56)	-18.4 (.82)	.005 (.55)
Wheat 36 states	53.32 (3.22)	-.087 (1.93)			.065 (1.63)	-.0031 (6.91)	.418 (7.63)	1.41 (3.65)	.010 (2.84)	.027 (5.86)	-.0045 (1.16)		-.001 (2.43)
Corn 39 states	-24.14 (1.73)		-.261 (3.93)	-.111 (2.78)	.329 (3.14)	.0040 (4.62)		.646 (9.28)	.0094 (1.14)	-.026 (2.56)	-.0047 (1.03)	32.02 (1.5)	-.008 (1.32)
Corn 39 states	27.52 (1.76)	.030 (.33)			.352 (6.26)	2.71 (2.24)	.100 (.596)	5.24 (3.11)	.0038 (.60)	.0081 (.73)	.0027 (.64)		.004 (.26)
Sorghum 23 states	75.05 (5.44)		-.26 (3.26)	-.301 (.91)	.133 (.799)	-.0013 (1.31)		.379 (5.33)	(.0027) (.11)	.0078 (.340)	.421 (.658)		

Numbers in parentheses are t values.

Table 2.

Results of Changes in Yield per Acre for Sorghum, Corn and Wheat Using Park's Method for Pooled Cross-Sectional and Time Seri
Data

Change in Yield	Con- stant	$\frac{PF_{t-1}}{PO_{t-1}}$	PF_{t-1}	PO_{t-1}	Sept. Weather	Har. Acres	Weighted Land	Irr. Acres	Change in Assets	Res.	O.S. Res.	D1	D1* O.S. Res.
Sorghum 23 states	-12.577 (1.52)		.009 (.666)	.418 (.113)	.099 (1.98)	.504 (1.48)		-.052 (.112)	-.016 (1.47)	.0089 (.151)	.0229 (.159)	-2.04 (1.92)	
Sorghum 23 states	-35.45 (5.37)	.081 (4.23)				.303 (.68)	-.084 (1.81)	.264 (.489)	.847 (.08)	.0037 (.731)	.152 (5.28)		.0066 (.587)
Corn 39 states	-25.14 (3.82)	-.033 (1.35)			.211 (11.69)	-.476 (.20)		.586 (1.65)	.019 (6.19)	.0001 (.11)	.0014 (.71)	12.49 (1.40)	-.003 (1.01)
Wheat 36 states	-15.49 (1.83)		-.020 (.82)	.368 (.763)	.078 (2.93)	.305 (1.06)		.251 (1.17)	-.0047 (.21)	-.0013 (.463)	.0044 (1.76)		

Numbers in parentheses are t values.

Although most of the hypothesized variables were significant at the 5% level of significance, there were some disappointments in these preliminary results, most notably in the research variables. The with-in state research variable was consistently significant in the wheat model. The outside research or "spill-in" variable as currently specified consistently had negative coefficients. An interaction term between the research budgets of the five top producing states of each commodity and the group of smallest producing states was tested but did not indicate a strong relationship of spillover in this direction. Further research effort will be directed towards other possible classification of states and areas as possible producers and consumers of research spillovers. Other specifications of the outside research variable will also be attempted.

Conclusions and Further Research

The results presented in this paper are very preliminary and are used at this point to illustrate the methodology. Further efforts need to be directed toward refining several of the explanatory variables such as weather and fertilizer. Since a primary feature of this study is an investigation of research spillovers, additional specifications of this variable need to be developed and tested. Other possible approaches are to incorporate within-region research expenditures of neighboring states and to utilize geoclimatic regions. An additional spillover topic is the issue of transferability of research results between similar commodities such as corn and sorghum and supporting research on it such as pest and weed control. Our future research plans are to investigate this type of spillover as well. Further refinements of these models will enable an assessment of individual lines of agricultural research and transferability of research activities.

Footnotes

1/See Kmenta, p. 508 for further development.

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Appendix A

Variables Used in Individual Crop Models

1. a) Yield--Yield per harvested acre. Values given in the *U.S. Agricultural Statistics* were used.
   b) Yield Change--The year to year change in the absolute level of yields per acre.
2. Price of Output--The national average price for each commodity. Available in *Agricultural Prices*.
3. a) Price of Fertilizer--Regional price values for N (anhydrous ammonia), P (Super Phosphate), and K (M of Potash) weighted by average amounts of N-P-K applied to each crop in each state. These fertilizer levels are listed in *Fertilizer Situation* and are based on surveys. Prices are available in *Agricultural Prices*.
   b) A regional Index Value of fertilizer and pesticide inputs was also used. Available in *Changes in Farm Production and Efficiency, 1978.*

   b) Irrigated Acres--Irrigated farm acres by state. Available for census years from the 1969 and 1974 Census of Agriculture and interpolated for individual states between census years.
   c) Weighted Land--An average value per farm weighted by pasture, forest, irrigated, and non-irrigated cropland in each state. Values were developed by Davis for census years and interpolated for between census years.

5. Weather--Pasture and range conditions on June 1 and Sept. 1 by state. Index values are available in Agricultural Statistics, and are based on subjective evaluations by state crop reporting personnel.
6. Change in Assets--Year to year change in total machinery assets on farms for states. Available in Balance Sheet of the Farming Sector, 1979.
7. State Size Shifter--Slope dummies of states that are relatively small producers of each commodity. States with production between 1,000 and 100,000 acres are in this category. The Crop Reporting Board already excludes a number of states with smaller levels of production.
8. a) Research--Total expenditure on research ($1,000) for each commodity from Inventory of Agricultural Research FY 1967-1977. These values were lagged four and five years.
   b) Outside Research--Formulated as the total expenditure on research for a commodity by the top five national producers of that commodity. Also available from Inventory of Agricultural Research FY 1967-1977. These research expenditure values were deflated with a weighted index composed of average salaries of college and university teachers (AAUP Bulletin) and the implicit price deflator for government purchases of goods and services.

MEASURING RETURNS TO RESEARCH EXPENDITURES FOR CORN, WHEAT AND SOYBEANS

W. B. Sundquist, Cheng-Ge Cheng and George W. Norton*

Introduction

A wealth of information exists on ex post returns to research investments for agriculture in the aggregate and for several agricultural commodity groups of commercial importance in the United States. Many of the investments made in agricultural research and, consequently, many of the allocative decisions on research funding, are, however, commodity-specific. Probably the main reason for the limited empirical literature on returns to commodity-specific research is that of the limited production input data available for individual commodities. Data from the U.S. Census of Agriculture, for example, do not permit commodity disaggregation beyond that employed by Bredahl and Peterson. Their analysis which utilizes commodity groups including cash crops, dairy, livestock, and poultry, has been updated by Norton using 1974 Census data. The research reported in this paper represents "early stage" progress in an effort to extend the cross-sectional production function-type analyses of Bredahl, Peterson, and Norton to three specific crops--corn, wheat, and soybeans. The production functions estimated are for the 1977 crop year.

Model, Variables and Data

The functional form used for each commodity is the familiar Cobb-Douglas production function. Specification of individual variables in the functions is shown in Appendix A. Since the U.S. Census of Agriculture does not report production input categories for specific agricultural commodities, we undertook to find alternative data sources from which we could develop commodity-specific production function formulations using individual states as observations. One source of such data is that provided in the nationwide set of farm enterprise budgets developed by Krenz, et. al., in the National Economics Division, ESCS, USDA. These so-called FEDS budget data have been developed annually since 1974 for all production areas in the United States for which the major farm commodities are produced commercially. The FEDS enterprise budget data are developed, drawing heavily on survey data, for each major substate production area though in some cases, such areas are specified as an entire state. We have weighted and aggregated these enterprise data for 1977 in a manner so as to develop category totals for each state.

While the FEDS budgets are readily available as a data source, they are not without some serious shortcomings for production function analyses. For example, the machine and labor inputs for a specific enterprise budget include, as is desirable for our purposes, only the machinery and labor that are used for that enterprise. But, these input categories have a high degree of multicollinearity within the total set of enterprise budgets for each crop because, though based on farm survey data, they depict a fairly uniform complement of machinery and a fairly standardized set of production practices. Moreover, the machinery and labor input categories are highly correlated with land because each acre of land used for production of a specific crop has a rather standard package of machinery and labor inputs applied to it. Thus, high intercorrelations between these input categories results. And, the budget data, being weighted estimates of per-acre means for each state, do not depict the full variance which is actually present among input categories on individual farms.

Though the above mentioned high intercorrelations between production input categories cause problems in estimating production functions using these categories of land, labor, and machinery as independent variables, this problem increasingly exists even independent of the FEDS set of data. Much of the per-acre variance in input categories between individual farms, state subregions, states, and multi-state regions has disappeared over time as commercial farmers have developed farming operations which are highly mechanized and fairly standardized. And, very little

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inputs has vanished as the shift to mechanized and otherwise modernized production methods on commercial farms in the United States has become virtually complete. And, this phenomenon will be reflected in the data on input categories whatever their source.1/ If, in fact, labor, machinery, and land inputs are approaching the relationship of technical complements, the only feasible solution to the statistical estimation problem caused by multicollinearity may be that of using a single input category as a proxy for the several or, alternatively, this can be accomplished by converting each of the several categories into single composite measure (dollars) and using the aggregate value of this new input variable.

The research variable included in the production functions for 1977 is an average of 1970-72 research expenditures for each crop from the CRIS data. Centered on 1971, the research expenditures are thus lagged six years from the 1977 production year. Research expenditures for corn average $330,000 with a range of more than $1 million for the 23 states included in the analysis. Iowa, Indiana, and Illinois are the top three states in corn research expenditures. These states are also the top soybean research states, along with Arkansas. Soybean research expenditures average $211,000 for the 26 states included in the analysis with a range of $500,000. Kansas and North Dakota are the top wheat research states in terms of expenditures. The mean wheat research expenditure is $185,000 for the 34 states included in the analysis with a range of $868,000. Data sources for the production functions are shown in Appendix Table B.

Regression Results

Initial production functions were specified for each crop for 1977 using state observations in order to estimate total crop value as a function of land, rainfall, fertilizer, chemicals, pesticides, labor, machinery expenses, and research expenditures (see Table 1). July rainfall was

iod for wheat due to the presence of both spring and winter wheat. Moreover, growing seasons and crop maturity dates vary significantly between individual spring wheat production areas and between individual winter wheat areas. And, temperature is also likely to be quite important. Fertilizer is significant in both the corn and wheat equations but not in the soybean equation. This may be due, in part at least, to the ability of soybeans to fix nitrogen.

The chemicals variable is not significant in any of the equations. This is not surprising because pesticides are normally applied in greater quantities in areas where pest problems are more serious. Since no data are available on the severity of the pest problem, there is, in effect, a specification error which biases downward the effect of the chemicals variable and reduces its significance. Also, as previously mentioned, there is a high degree of multicollinarity among chemicals, fertilizer, labor, land, and machinery in the FEDS data set. The coefficients for the latter three variables are not significant in these three equations with the exception of land in the soybean equation. Research is not significant in any of the equations. It too, however, is highly correlated with the land, labor, machinery, fertilizer, and chemicals variables.

Before attempting to deal with the problem of multicollinearity, an effort was made to account for major differences in land quality among regions through a set of crop-specific regional slope dummies on the land variable. These dummies are defined in Appendix C. No significant differences were found for corn, but the Northern and Southern Plains regions showed significantly lower quality land than the Corn Belt region for wheat (see Table 2). And, the Southern and Delta regions showed lower quality land than the Corn Belt for soybeans.

Table 1. Initial Research Production Functions*

	Land	Labor	Machinery	Fertilizer	Chemicals	Rain	Research	Constant	$\bar{R}^2$
Corn	.24	.18	.30	.34	-.03	.19	-.03	1.84	.994
	(1.68)	(.85)	(1.69)	(5.17)	(-.37)	(8.24)	(-.60)	(4.09)	
Wheat	.288	.18	.16	.37	.019		.049	1.48	.955
	(1.01)	(.91)	(.56)	(3.76)	(.64)		(.73)	(1.35)	
Soybeans	1.77	-.97	.23	-.046	.022	.035	-.01	-.43	.977
	(4.13)	(-1.65)	(.286)	(-.68)	(.23)	(.63)	(-.11)	(-.26)	

*Numbers in parentheses are t-values.

	Corn	Wheat	Soybeans
Land	.21	.082	.480
	(.95)	(.24)	(1.44)
Fertilizer	.29	.14	-.014
	(3.56)	(.94)	(-.313)
Chemical	-.03	.025	-.076
	(-.38)	(.75)	(-1.35)
Labor	.06	.48	-.475
	(.20)	(2.16)	(-1.16)
Machinery	.55	.34	1.17
	(2.17)	(1.06)	(2.35)
Rain	.19	--	.068
	(7.9)	--	(2.02)
Research	-.025	.07	-.047
	(-.49)	(.92)	(-.83)
Slope 1	.007	-.02	-.032
	(1.12)	(-1.68)	(-3.40)
Slope 2	-.007	-.013	-.01
	(-.93)	(-.82)	(-1.01)
Slope 3	--	-.05	-.041
	--	(-2.45)	(-5.62)
Slope 4	--	-.039	--
	--	(-1.95)	--
Slope 5	--	-.026	--
	--	(-1.40)	--
Constant	1.1	.357	-5.127
	(1.6)	(.256)	(-4.37)
$\bar{R}^2$	.994	.960	.993

*Numbers in parentheses are t-values.

In an effort to reduce the multicollinearity problem mentioned above and with the likelihood of a high degree of technical complementarity existing among them, the land, labor, and machinery variables were value weighted and added together. Land quality dummy variables were no longer included because the use of land price weights was assumed to pick up at least some of the land quality differences. Functions were re-estimated for corn, wheat, and soybeans and the results are shown in Table 3. While the land-labor-machinery aggregate was highly significant in the wheat and soybean functions, it was not significant in the corn equation. The chemicals variable increased in significance in all cases while rainfall and research both increased in significance in the wheat equation. A large amount of multicollinearity still exists, however, among chemicals, fertilizer, research, and the land-labor-machinery aggregate variable.

machinery, chemicals, and fertilizer, were value aggregated. This input aggregate was included in a production function with rainfall and research as the other independent variables (see Table 4). In this case, the traditional variable aggregate is highly significant for each crop. Rainfall was significant at the 95% level for corn and wheat. Research had a positive coefficient in all cases and was significant at the 95% level for wheat, and the 90% level for soybeans. The research coefficients were roughly of the same magnitude for each of the three crops.

Additional regressions were run in which a "spillover" variable was added in an attempt to pick up the spillover effects of research across state boundaries. While spillover of research occurs for all three crops to some extent, it is thought to be most pronounced, or at least of a different form, for soybeans because varieties are very latitude specific. Varieties raised in Iowa, for example, are also raised in Pennsylvania. Any simply constructed spillover variable is, of course, somewhat arbitrary and open to criticism. But, inclusion of even a crude variable seems preferable to ignoring the existence of spillover. The specification used in this study is described in Appendix A. The results of adding a spillover variable to the production function are shown in Table 5.

These results indicate that inclusion of the research spillover variable improved the soybean and wheat functions substantially but the crude specification of the spillover variable for corn was not a particularly useful addition to the function for that crop.

The specified research spillover variable for soybeans is highly significant. It has a t-test of 4.51 and the adjusted R^2 for that equation increases from 0.886 to 0.940. The research coefficient itself decreased from 0.28 to 0.23. Other specifications for the soybeans equation were tried with the spillover variable included and the coefficient of the research variable for soybeans remained highly significant and stable.

The addition of a research spillover variable for wheat increases the R^2 for the wheat function slightly from that of Table 4 and it strengthens the significance of the rain and research variables in the equation while leaving the coefficient on the "traditional inputs" variable highly significant.

	Land, Labor, Machinery	Fertilizer	Chemicals	Rain	Research	Constant	$\bar{R}^2$
Corn	-.14	.78	.37	.28	-.08	3.54	.962
	(-.95)	(3.98)	(2.35)	(5.29)	(-.79)	(3.40)	
Wheat	.47	.31	.12	.03	.12	.75	.948
	(4.91)	(2.63)	(4.78)	(1.86)	(1.82)	(.85)	
Soybeans	.58	-.10	.31	.20	.06	-3.83	.889
	(3.56)	(-.76)	(1.63)	(2.46)	(.28)	(-2.61)	

*Numbers in parentheses are t-values.

Table 4. Research Production Functions with all Traditional Variables Aggregated*

	Land, Labor, Machinery, Chemicals, Fertilizer	Rain	Research	Constant	$\bar{R}^2$
Corn	.72	.33	.20	1.98	.883
	(5.16)	(3.80)	(1.20)	(1.09)	
Wheat	.75	.02	.27	-.17	.899
	(8.69)	(.94)	(3.37)	(-.14)	
Soybeans	.66	.26	.28	-4.63	.886
	(5.25)	(3.50)	(1.74)	(-3.25)	

*Numbers in parentheses are t-values.

Table 5. Research Production Functions with Research Spillover Variable*

	Land, Labor, Machinery, Chemicals, Fertilizer	Rain	Own Research	Research Spillover	Constant	$\bar{R}^2$
Corn	.68	.34	.20	.06	1.89	.878
	(4.26)	(3.76)	(1.22)	(.53)	(1.02)	
Wheat	.67	.02	.27	.14	-.249	.914
	(7.75)	(1.07)	(3.57)	(2.49)	(-.22)	
Soybeans	.64	.15	.24	.33	-7.95	.940
	(6.93)	(2.63)	(2.01)	(4.51)	(-6.25)	

*Numbers in parentheses are t-values.

Notwithstanding the danger of placing too much confidence in the exact size of the research coefficients, the coefficients from Table 5 were utilized to compute the marginal products of experiment station research. Estimates of national marginal products of research for corn, wheat, and soybeans are obtained by multiplying the research coefficient for each commodity by its respective average product of research.2/ These estimates were then prorated or discounted by dividing them by three to take account of the contributions of extension and private research. Arguments supporting this procedure are presented in Bredahl and Peterson but alternative proratings of benefits are easy to make and it seems unlikely that the proportional contribution of public research is less than that of private research or extension. The resulting long-run marginal product approximations are shown in Table 6.

Table 6. Marginal Products and Internal Rates of Return*

	Marginal Products	Assumed Lag	IRR(%)
Corn	97	6	115
Wheat	59	6	97
Soybeans	103	6	118

*Calculated from the equations in Table 5 which include spillover variables for all three crops. IRRs calculated from equations in Table 4 (without spillover variables) differ only slightly in magnitude from these.

The calculation of internal rates of return3/ requires that the future returns be discounted. A mean lag of six years is assumed for research on each of these crops. This is consistent with empirical studies such as Evenson's on the length of the lag. Breeding research probably has a somewhat longer lag but other types of crop research probably have a shorter lag. Two facts stand out with regard to the IRRs shown in Table 6. First, they are extremely high and, even if discounted severely for possible error, suggest underfunding of public research for these crops. Second, the IRR is of the same general order of magnitude for each crop. The latter fact suggests that research dollars are probably being allocated reasonably efficiently among the three crops. Moreover, the interstate allocation of research dollars for the three crops appears consistent with the relative economic importance of the three crops at least for those states where these specific crops are of major economic significance.

The regression results presented in this paper illustrate the data problems involved in trying to use the production function approach in individual commodity research evaluations. Yet, decisions relative to the allocation of research funds are often commodity-specific and even specific to such research functions as plant breeding, analyses of the effects of soil fertility, mechanization of production and/or harvesting, disease and/or insect control, improved marketing systems, etc. And, where feasible, efforts to evaluate the results of these and other lines of agricultural research provide additional insights into the potential payoff for alternative research expenditures.

One should not place excessive confidence in the exact size of the research coefficients reported in Tables 4 and 5 or in the internal rates of return calculated from them (Table 6) due to the possible specification error resulting from the aggregation of several input variables. Also, we are measuring returns to an annual flow of research expenditures when a portion of these returns might reasonably be attributed to prior period investments in the research system and/or to investments in more basic or general purpose research. Moreover, our measure of output is for a single year only and it will vary some between years. With these cautions in mind, we believe that the evidence indicates that returns to agricultural research continue to be high and well in excess of their investment cost. Moreover, the returns to research on corn, wheat, and soybeans are high and funds appear to have been allocated reasonably efficiently across these crops in the early 1970s. The exact magnitude of those returns, however, is open to some question because of data problems for inputs and uncertainty as to the contributions of private research and to the education and information dissemination functions.

Finally, we conclude at this stage of our analysis that the most useful estimates of research returns for individual crops are probably obtained via a production function formulation which aggregates all or most traditional production inputs4/ but which provides for separate specification of major weather effects and research expenditures, the latter including some operational measure of spillover between geographical areas. In our judgment, improved specification of weather and research spillover variables should be the subjects of additional research. If feasible, so should the separation of genetic-related research from that of improved cultural and husbandry practices. And, the current controversy relative to displacement of labor via mechanization suggests a strong case for separating out mechanization research. We believe, however, that the latter is probably a more relevant issue in the labor-intensive specialty crops than for corn, wheat, and soybeans.

exist between land, labor, and machinery on a per farm basis for aggregate cash grain in the 1969 and 1974 Agricultural Census data:

	1969			1974	
	Machinery	Land		Machinery	Land
Land	0.77		Land	0.90	
Labor	0.46	0.80	Labor	0.73	0.61

2/Geometric mean levels of output and research are used in calculating the average products.

3/Previous authors have used varying formulas for computing the IRRs to research (Davis). Differences in these formulas stem from the assumptions made about the distribution of benefits over time. In this study the assumption was made that all benefits occur in the sixth year after the research expenditures which should provide underestimates of the IRRs.

4/We are also exploring other alternatives, including the use of ridge regression techniques, to deal with the problem of high intercorrelations among independent (input) variables.

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{2} Davis, J. Stability of the Research Production Coefficient for U.S. Agriculture. Unpublished Ph.D. Dissertation, University of Minnesota, 1979.

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APPENDIX A--VARIABLES FOR INDIVIDUAL CROP PRODUCTION FUNCTIONS

Variable

1. Output - Total value of crop sold
Multiplied each state's production by national average price. USDA publication Crop Production, Annual Summary gives production data and USDA publication Crop Values gives price data.

2. Land - Area planted to crops
Found in USDA publication Crop Production, Annual Summary.

3. Labor - Value of labor
Multiplied hours of machinery labor from "FEDS" budgets by farm wage rate for the United States found in USDA publication Farm Labor.

4. Fertilizer - Average U.S. prices for N, P, and K used to sum up N P & K into one variable. These prices were found in USDA publication Costs of Producing Food Grains, Feed Grains, Oilseeds, and Cotton.

5. Chemicals - Value of herbicides and insecticides from FEDS crop budgets deflated by the price of the appropriate herbicide and insecticide for each crop. For example, the corn herbicide value was deflated by the ratio of the national to the state price of atrazine.

6. Machinery - Sum of (1) fuel and lube, (2) service flow of machinery stock and (3) custom hire of machinery
(1) Fuel and lube - Value of fuel and lube from crop budgets deflated by the weighted national average price of gasoline and diesel fuel divided by the weighted state price of gasoline and diesel fuel in each state.
(2) Ownership costs from FEDS budgets.
(3) Custom hire from FEDS budgets.

7. Weather - July rainfall (deviations from normal).

8. Soils - Slope dummies on land variables based roughly on 1957 Yearbook of Agriculture land groups, for wheat and more aggregated groups for soybeans and corn.

9. Research - Total expenditure on research for particular commodity from Inventory of Agricultural Research FY 1970-1972 average.

10. Research Spillover - Soybeans: Research expenditures on soybeans for other states at the

production-weighted proportion of that state's research is included in the spillover variable.

Corn and wheat: Research expenditures on corn and wheat for bordering states which fall within the same geoclimatic region. The wheat regions were based on those delineated by Davis and the corn regions were based on corn maturity zones. If only a portion of a bordering state is included in the same geoclimatic region, a production-weighted porportion of the state's research is included in the research variable.

APPENDIX TABLE B
DATA SOURCES

1. United States Department of Agriculture, *Agricultural Statistics*, 1971, Washington, D.C.

2. __________, *1977 Annual Prices Summary*, Crop Reporting Board, ESCS, USDA, June 1978.

3. __________, *Cost of Producing Selected Crops in the United States - 1976-1977 and Projections for 1978*, ESCS, USDA, March 1978.

4. __________, *1978 Crop Production, Annual Summary*, Crop Reporting Board, ESCS, USDA, January 1978.

6. __________, *Farm Labor*, Crop Reporting Board, ESCS, USDA, February 1978.

7. __________, *Farmers' Use of Pesticides*, ESCS, Ag Economic Report No. 418, 1978, Washington, D.C.

8. __________, *Inventory of Agricultural Research, FY 1970*, Vol. II, Science and Education Staff, 1970.

9. __________, *Inventory of Agricultural Research, FY 1971*, Vol. II, Science and Education Staff, 1971.

10. __________, *Inventory of Agricultural Research, FY 1972*, Vol. II, Science and Education Staff, 1972.

11. __________, *Federal Enterprise Data System*, 1977 budgets, ESCS, USDA, (obtained from Ronald Krenz, Oklahoma State University).

12. __________, *The Yearbook of Agriculture 1957, Soil*, USDA, Washington, D.C.

13. __________, Unpublished data on deviation from normal July and annual rainfall provided by Michael Weiss at USDA.

APPENDIX C:
States Included in Land Dummies

Wheat: 34 states

Slope 1. KY, MD, N.Y., N.C., PA, TENN, VA
Slope 2. ALA, ARK, GA, MISS, S.C.
Slope 3. COLO, KANS, OKLA, TEX
Slope 4. MONT, NEBR, N. DAK, S. DAK
Slope 5. ARIZ, CALIF, IDAHO, N. MEX, OREG, WASH
Land ILL, IND, IOWA, MICH, MINN, MO, OHIO

Corn: 23 states

Slope 1. DEL, KY, MD, N.J., N.Y., N.C., PA, TENN, VA
Slope 2. COLO, KANS, NEBR, TEX
Land ILL, IND, IOWA, MICH, MINN, MO, N. DAK, OHIO, S. DAK, WIS

Soybeans: 26 states

Slope 1. ALA, GA, OKLA, S.C., TENN, TEX
Slope 2. DEL, KY, MD, N.J., N.C., VA
Slope 3. ARK, LA, MISS
Land ILL, IND, IOWA, KANS, MICH, MINN, MO, NEBR, OHIO, S. DAK, WIS

TECHNOLOGY SELECTION AND APPROPRIATE TECHNOLOGY

A. Steven Englander*

This paper provides a formal model of technology choice by a single region. Case studies have indicated that the technology acquired by LDCs often seem unsuitable, although the criteria for suitability are often unclear. The reasons which are presented for inappropriateness of the selection often rely more on political arguments then economic ones, or treat the recipient country as a passive actor in the whole process.

Can a technology actively selected by a recipient country ever by inappropriate, assuming factor cost ratios represent true relative values? A model presented by Evenson and Bingswanger (1978) indicates that a technology developed in one economic or physical environment may be 'appropriate' to a second, very different environment if the second environment can generate a very limited range of technological possibilities on its own. Ranis (1978) has emphasized the importance of information on technological alternatives flowing smoothly and accurately within the system and the need to acquire capacity for adaptive research. Both these approaches recognize the importance of indigenous research capacity, although Ranis accords more emphasis to friction and proper incentives within the system. Barring policy and management problems, their conclusions appear to be that technology choice will be efficient--the appearance of inappropriateness stems from the lack of explicit recognition of the contraints on technology generation in the system.

The model presented below builds on the early models of rational technology selection of Evenson-Binswanger and Ranis. It shares common elements with the Evenson-Binswanger model and may be regarded as a generalization of their model. It goes further, however, in several crucial aspects. It allows the extent of both adaptive and independent research to be choice variables in the technology acquisition decision. It allows for selection out of a continuum of technologies which differ in the environments for which they were designed. It allows for limits to the extent to which technologies can be adapted across environments and allows for losses because of imcomplete adaption. The public goodnature of research plays a critical role in determining the efficiency of resource allocation as well.

The model presented immediately below is couched in terms relating to agricultural technology. A reason for first presenting a model of agricultural technology selection is that many of the conceptual issues possess more intuitive natural interpretations. A second section will consider the impact of market structure on the development of technology, and a third section will broaden the basic model of agricultural technology development to one which emcompasses certain types of fixed capital investment. A fourth section discusses testing of the model.

Technology Choice in Agriculture

In the model below, the decision is made by a region as to whether to adopt technology produced in other regions or build up a stock of indigenously developed technology. The region assumes that its research policies will not affect those of any other region. In practice, especially internationally, such behavior seems the rule rather than the exception. The focus is the consideration which enter into the technology acquisition decision for a single country, not efficiency in resource allocation among a set of countries.** In discussing the transferability of technology, we can use the environmental-sensitivity measure devised by Evenson and Binswanger, which relates cost of production with a given technology in its native environment to cost of production in another environment in which it is used. The meaning of the term "environment" is also clear. In the agricultural context,

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[**] For discussion of this topic, see Englander, and Evenson (1979) and Englander (1980).

For the concreteness it will be assumed that water control is the relevant environmental dimension, that environments range from desert to well irrigated, and that the percent of seasons without drought problems measures water control. Any relevant environmental dimension or an index combining several dimensions could serve as well.

Assume that research has been successfully conducted on varieties grown under various regimes of water availability. A country in which drought is a problem most of the time is attempting to choose its research priorities. It has a traditional agricultural technology which is very resilient under drought conditions but which is lacking in other dimensions. The choices available to the country are (a) ignore the research of the other regions and conduct research independently according to its own priorities and abilities and (b) adapt the research of other regions to the domestic conditions of drought.

A number of factors will determine its decision. The first is the distribution of research which is available from regions under differing water regimes. Irrigated and well-watered regions may have a preponderance of the available research and the technologies developed in these regions may have very desirable characteristics. However, the difficulty in incorporating resistance to severe drought conditions into these technologies may commend adapting a smaller research stock available from a region in which drought resistance is a greater priority.

On the other hand, it may remain advantageous to sacrifice a degree of drought resistance in order to acquire a technology which is better in other ways. However, the impact of a diminishment in the level of drought resistance on the advantages of technology superior in other dimensions must be considered. As an imported technology becomes more susceptible to drought, the benefits from improvements in other dimensions will be reduced according to the increase in damage from drought.

In making the decisions discussed above, the availability of research resources for adaptive and independent research must also be considered. If there are large numbers of well-trained researchers willing and able to create technologies specific to their environment, the technology acquired by the region, both adapted and created indigenously, will be closely tailored to the domestic environment. If such capacity is absent, there will be less concern about the completeness of adaptation since the role of independent research will be less significant relative to the research imported.

i'th and k'th environments.

The availability of research across all other environments is expressed by

$$X_j = X_j(E_{jD}),\ X_j' > 0,\ X_j'' < 0 \tag{1}$$

where j ranges over the extent of the environmental index. It will be assumed that there are increasing amounts of research available with greater environmental distance from the domestic region, but that the rate of increase is falling.

The extent to which research can be transferred from environment j to environment k is determined by

$$t_{jk} = t_{jk}(E_{jk})\quad t' < 0,\ t'' < 0 \tag{2}$$

i.e., as a function of the distance between the original environment to which the research was tailored and the environment to which it is being adapted. The extent of transferability is assumed to decline at an increasing rate as the distance between the original environment and the target environment increases. Thus, $t_{jf}X_j$ measures the total technology transferable from environment j to environment f.

The cost of incompletely adapting a stock of research available from a distant environment is the sacrifice of some environmental specificity of research. As a region compromises on the extent to which it adapts technologies to its region, it is likely to be lowering the usefulness of the technology which it has acquired. An illustration can be drawn from the water availability example discussed above. If traditional technologies are drought resistant but the newly acquired technology is not as resistant, the effectiveness of the acquired technology stock will be diminished by the extent of the added losses from drought. The reduction in research effectiveness is described by

$$a_{fd} = a_{fD}(E_{fD}),\ a_{fD}' < 0\ a_{fD}'' < 0 \tag{3}$$

where E_f is the environment to which the technology is adapted, and E_{fD}, therefore represents the extent to which the domestic region has compromised in tailoring the technology to its environment. The less the technology stock is tailored to the domestic environment, the lower the value of the stock. It is also assumed that the decline in the usefulness of the technology becomes steeper as it is less adapted. Below, when we discuss the degree of adaptation of a technology, we will be referring to the value of a_{fD}.

If a technology developed in environment j is

$a_{fD} t_{jf} X_j$

Implicitly, this scheme disaggregates a technology package into two components. One component consists of characteristics of the technology which are relatively insensitive to environmental changes. The environmental sensitivity of any element in the technology package will be determined specifically for each region seeking to acquire technology, and will vary between regions. It is on the environmental-sensitive elements that adaptive research is conducted, and the degree to which the sensitivity is eliminated determines the extent of adaptability to the domestic region.

It is assumed that the orientation of independent domestic research is determined in conjunction with the decisions on the transfer of technology, and that the two complement each other. The former, however, is constrained by the degree of adaptability which has been built into technology acquired from other regions and will decline in usefulness the less the technology as a whole is adapted to the domestic region. In the example in which water availability is the relevant environmental index, if transferred technology has not been rendered adequately drought resistant by adaptive research, the effectiveness of technology developed domestically will suffer to the same extent. This is equivalent to the assumption that technologies combined from different sources will jointly have the minimum of their levels of adaptability. In this case, domestic research may be assumed adapted to the domestic environment but limited by the adaptability built into the transferred research. This is probably a conservative assumption. Many of the results will hold qualitatively even with more liberal assumption on the joint adaptability of technologies acquired from diverse sources.

The four decision variables are (1) the environment whose technology is to be transferred, E_j; (2) the extent to which the technology is to be adapted to the conditions of the domestic regions, E_{Df}; (3) the level of adaptive research, X_1; and (4) the level of research aimed at improving upon the acquired technology, X_2. If there is no attempt at transferring research, then only independent research, directed at improving existing technology in the domestic region, is conducted.

The formal maximization problem may be written as

$$\max L = g \left\{ a_{fD} \left[t_{fj} \quad 1-e^{-\rho X_{1D}}) X_j + X_{2D} \right] - C(X_{1D}, X_{2D}) \right\}$$

C (.,.)	is the cost function of the two research types,
X_{1D}	is the level of adaptive research conducted by the domestic region acquiring research,
X_{2D}	is the level of the independent research activity in the domestic region,
a_{fD}	is, as discussed above, the relative effectiveness of research, which depends on the degree to which the transferred research has been adapted to the domestic environment,
X_j	is the research available in region j,
and ρ	is a parameter which determines the ability of adaptive research to transfer research.

In the argument for g (.), the research benefits function, the term in square brackets represents a stock of research which the domestic region is attempting to utilize and the factor a_{fD} discounts this technology by the extent to which it is not adapted to the domestic region.

For simplicity, much separability has been incorporated into the functional forms. Thus, X_j is the transferable research of region j, $t_{fj} X_j$ is the maximum potential transfer of research from environment j to environment f, and $(1-e^{-\rho X_1})$ measures the percentage of the maximum potential transfer which is actually transferred. The point of this formulation is to introduce the effort directed at research transfer, the extent of adaptation and the distribution of potentially transferable research of factors in the determination of appropriate technology for the region.

It would also be possible to write the transferred research component as

$$(1-e^{-\tau_{fj} X_1}) X_j$$

where $\tau_{fj} = \tau(E_{fj}) \tau' < 0 \; \tau'' < 0$.

There is little qualitative difference in the results obtained using either form. The second form allows the adaptation of any technology to any environment as long as more adaptive research is performed. The earlier form is more amenable to graphical interpretation and is used in the presentation below.

The equilibrium conditions are presented below. ε (.) refers to the elasticity of . with respect to its argument and η_t is the percentage of total research acquired through transfer.

$$-\frac{\varepsilon(t)}{E_{fj}} = \frac{\varepsilon(X_j)}{E_{Dj}} \qquad (6)$$

$$g' \; a_{fD} = C^2 \qquad (7)$$

$$g' \; a_{fD} t e^{-\rho X_1} X_j = C^1 \qquad (8)$$

The conditions above are conditions for an interior solution. Examination of the nature of corner solutions provides some insight into conditions which will make a region rely entirely on transferred research or its own research. In (5), since η_t is bounded by one, if

$$\frac{\varepsilon(a_{fD})}{E_{fD}} > \frac{\varepsilon(X_{jt})}{F_{Dj}} = \frac{\varepsilon(t)}{E_{fj}},$$

then transferred technology is adapted completely to the domestic environment (or no transfer is attempted). From (6) if

$$\varepsilon(X_{jt})/F_{Dj} > \frac{\varepsilon(t)}{E_{fj}},$$

then the original environment of the transferred technology will be the one which has conducted the most research.

Figures 1 and 2 analyze some implications of these equilibrium conditions. The first quadrant of figure 1 illustrates (6). The values of $\varepsilon(X_j)$ and $-\varepsilon(t)$ are graphed against E_{fj} and E_{Dj}. From (6) locis of points of equilibrium are the points $\varepsilon(t)$ and $\varepsilon(X_j)$ which lie on the same ray drawn from the origin. For example, as the ray OR indicates, when $E_{Dj} = E'_{Dj}$, then $E_{fj} = E'_{fj}$. The former, E_{Dj}, is the distance of the domestic environment from the environment of origin of the new technology, and E_{fj} is the extent to which the technology has been adapted to the domestic environment. The distance between the equilibrium points is E_{fD}, the measure of the extent to which the borrowed technology has not been adapted to the domestic environment. The point S indicates the point where the transferred technology is completely adapted to the domestic environment. In quadrant IV, the equilibrium values of E_{fD} and E_{fj} are graphed. In quadrant III, $-\varepsilon(a)$ is graphed against E_{fD}. In quadrant II, the equilibrium values of $-\varepsilon(t)$ and (a) are shown as PP' and the equilibrium values of $-\varepsilon(t)$ and $\varepsilon(X_j)$ are shown as OQ.

In Figure 2, equilibrium values of $\varepsilon(X_{jt})/E_{Dj}$ and $\varepsilon(a)/E_{fD}$ are drawn. From (8) the increase of the slope of the ray drawn from the origin to any point along BB' can be seen to be the share of transferred technology in the total technology in Figure 2, because the implied share of transferred technology would be greater than one. It also indicates that the degree of adaptation to the domestic environment will diminish as the importance of transferred technology increases. Factors which could accomplish this would include reductions in the relative cost of adaptive research and outward shifts in research availability.

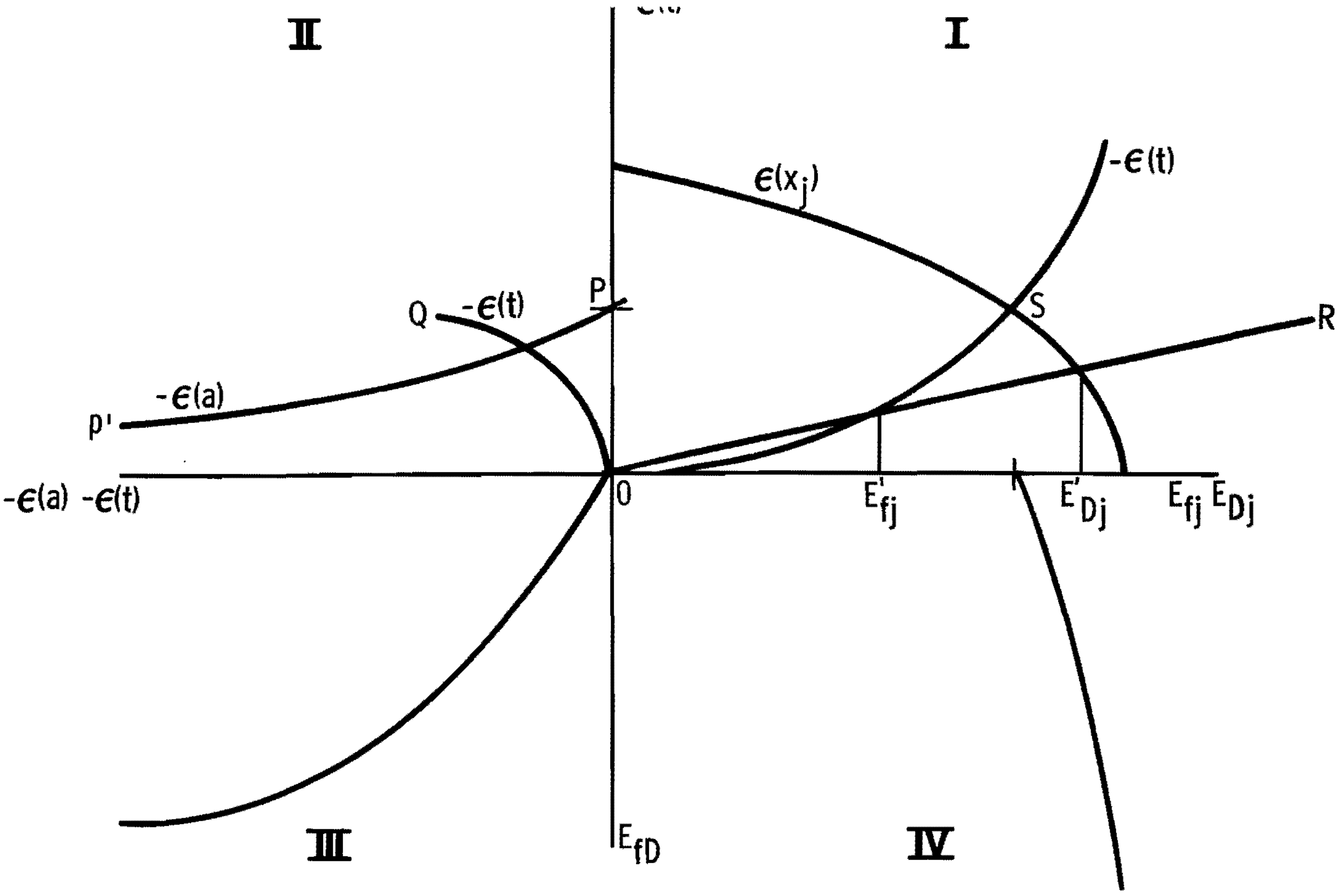
By taking the differentials of (5) and (8), it is possible to examine the effects of shifts in the underlying parameters. It is possible to show that a positive shift in the marginal cost of adaptive research will induce less adaptive research on but a greater degree of adaptation of a technology drawn from a nearer environment. The level of independent research will increase. On the other hand, an upward shift in the marginal cost of independent research will induce a lower level of independent research, a higher level of adaptive research, less adaptation to the domestic environment, and selection of a technology from a more distant environment. The negatively correlated movements of the level of adaptive research, X_1, and the extent of adaptation, a_{fD}, occur because the value of the latter depends heavily on the relative importance of independent and adaptive research. As independent domestic research gains more prominence, the extent to which a technology will be adapted to the domestic environment increases.

If other regions increase the transferability of their research, shifting the t schedule upwards and raising the maximum potential transferability from other environments, the effects will generally be similar to those resulting from a lowering of marginal costs of adaptive research. The exact sufficiency condition for these results is that

$$-\varepsilon(g') < \frac{1}{\eta_t}$$

where, as before, $\varepsilon(g')$ is the elasticity of marginal benefits and η_t is the share of transferred technology in the total of technology acquired. The intuitive explanation of this condition is that if marginal benefits fall very quickly, easier access to research performed by other regions may induce a cutback in the level of adaptive research. All benefits functions of the form

$g = Z^{\alpha}$ $0 < \alpha < 1$, where Z is the amount of technology acquired, fulfill the condition. Similar conditions and results emerge from an outward shift of the stock of research in other regions.



A shift in the a_{fD} schedule produces ambiguous effects. The interpretation of proportionate outward shift would be that the decline in the effectiveness of a fixed research stock as it becomes less adapted to the domestic environment becomes less severe. It is clear that the marginal productivity of both adaptive and independent research would increase, holding the other two choice variables fixed. It can also be shown that if the relative share of independent research decreases, then so will the equilibrium value of $\varepsilon(X_j)$, corresponding to an increased dependence on technology developed in a more distant environment. If the share of transferred research increases, then the value of $\varepsilon(a)/E_{fD}$ must fall. The direction in which shares move would seem to depend on whether the cost of independent research increases quickly relative to the cost and availability of transferred research.

The assumptions of negative second derivatives for the $a(E_{fD})$, $t(E_{fj})$ and $X_j(E_{Dj})$ functions made interior solutions more likely. The interpretations of these assumptions are (1) the marginal losses due to nonadaptation are increasing, (2) the marginal ability to adapt diminishes more rapidly the greater the distance over which adaptation is attempted, and (3) the marginal increase in technology as one moves to more distant environments is diminishing.

Altering the third of these assumptions to allow for increasing marginal research availability with greater distance could introduce increasing returns to scale so that a region's choice would be between adapting a larger but distant stock or not doing any adaptive research at all, eliminating intermediate choices. This could also be regarded as the Evenson-Binswanger case with discrete rather than continuous technology choice sets.

Some effects of altering the first two assumptions are illustrated in Figures 3 and 4. The effect of changing the second assumption is indicated by the solid lines, while the effect of altering the first is illustrated by the dashed lines and tildas. The most striking result is that in both cases the monotonic

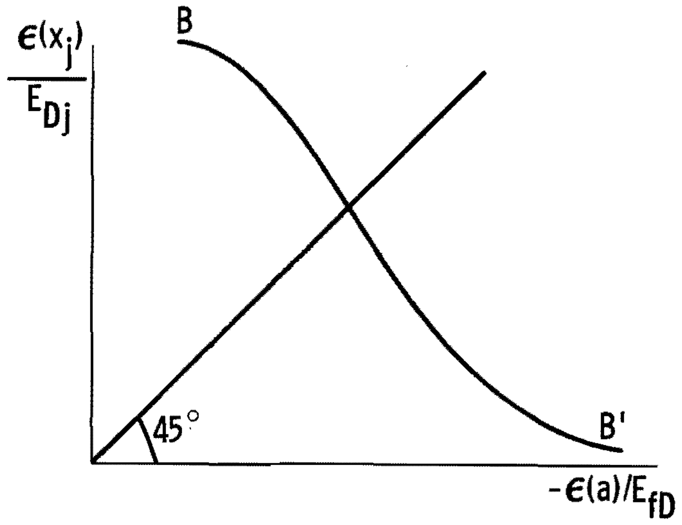


Figure 3.

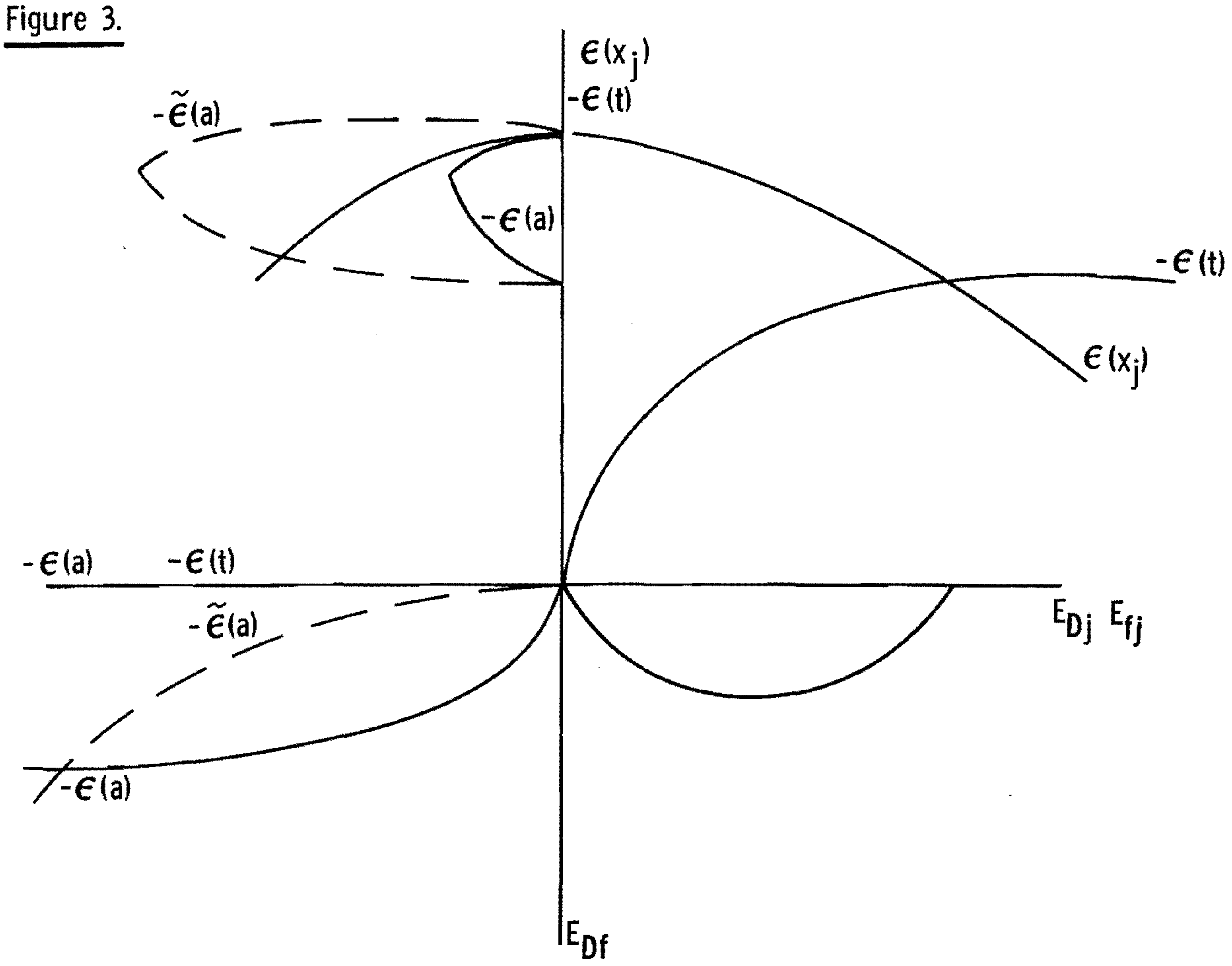
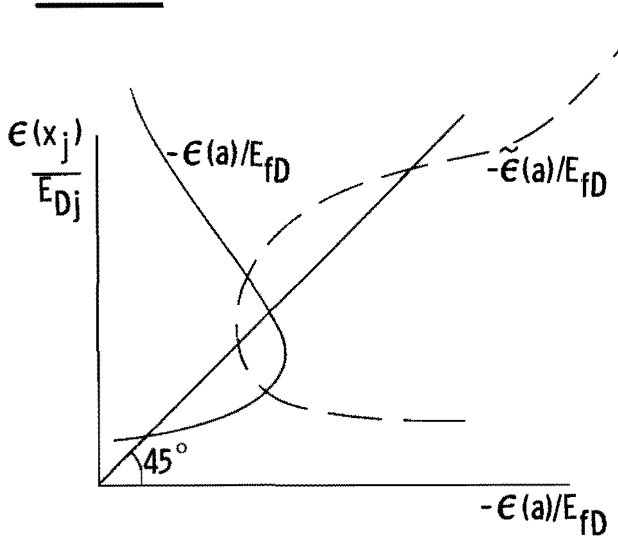


Figure 4.



equilibrium relationship of E_{Dj} and E_{Df} does not hold. Both extremely high and extremely low levels of research transfer will be associated with high degree of adaptation. Figure 4 expresses this somewhat differently, indicating that the relative importance of transferred research can be associated with two different levels of adaptability. The case illustrated by the solid lines in Figure 3 and Figure 4 can be interpreted as indicating that for any value of a_{fD} there will be two values of $\varepsilon(X)$ and $\varepsilon(t)$ which fulfill the equilibrium conditions, one which a large share of a small research stock may be transferred and a second in which a smaller share of a larger stock is available. Of these two values, one will provide a greater borrowable stock of research than will the other. For any value of a_{fD}, there will be only one efficient borrowable stock although the function relating equilibrium values of $\varepsilon(a)$ and $\varepsilon(X_j)$ need not be continuous. From Figure 4 it can be seen that of the possible equilibrium associated with any value of $\varepsilon(a)$, one will have a relatively greater emphasis on transfer and will have a more distant origin for the transferred technology than will the other possible equilibrium. As would be expected, such a system would tend to show much less regular responses to parameter shifts. In the case devoted in Figure 3 and Figure 4 by dashed lines and tildas, both t_{fj} and a_{Df} fall at a slower rate with higher values of their arguments. This case poses more complications than the one just discussed as there are likely to be potential equilibria at various combinations of extreme values of t_{fj} and a_{Df}.

Market Structure and Technology Choice

This section will consider the effect of market size on the amount and type of research which will be conducted. It is clear that the benefits of a new technology will be a positive function of the scale on which it is utilized. If the region acquiring new technology is small and homogeneous, facing elastic input supplies, it will be reasonable to associate increases in market size with outward shifts in the marginal benefits function of research. The focus of this section will be the expansion path of transferred and independent domestic research as the marginal benefits function is shifted outwards. The related, but not identical, question of how the composition of the research bundle will change as marginal costs change will also be examined. The latter issue can be related to the public good aspect of research. Although a particular region in a given environment may be interested only in its own benefits, the other regions which share the environment may come to recognize that, taken as a group, their access to research resources of mutual benefits is significantly greater than the availability of resources as perceived by each individually. The ability to benefit from the research of others may be regarded as lowering the cost of acquiring any level of research, assuming that the regions act in concert in acquiring the research.

Some of the earlier discussion is relevant to these problems. It was noted above that as the share of transferred technology increased, there would be a tendency to acquire technology from more distant environments but with less adaptation to the domestic environment. As well, there was a limit to the amount of research which was available for transfer from other environments, a limit which could stem from increasing amount of technology developed at those environments. The total of technology which becomes available to the region can be represented by Z, where

$$Z = a_{fD} \left[t_{fj} X_j (1-e^{-\rho X_1}) + X_2 \right]$$

and a_{fD}, t_{fj}, X_j, X_1 and X_2 are as defined above. Where no confusion will arise, the subscripts will be dropped in the future.

From the earlier discussion, it is known that the equilibrium values of a, t, and X_j are linked, as was illustrated in Figure 1. In fact, if we define

$$T^* = a^* t^* X_j^*$$

where the asterisks denote equilibrium values, it is easy to show that

$$\frac{dT^*}{T^*} = (1 - \eta) \frac{X_j'}{X_j} dE_f$$

where, as before,

$$\eta = \frac{t a X_j (1 - e^{-\rho X_1})}{Z}$$

and E_f measures the extent to which technology is adapted to the region.

It is also possible to show that in equilibrium the values of t and η increase with X_j while that of a declines. An increase in E_f lowers the value of a, but raises the equilibrium value of T*. We can also define

$$T \equiv T^* (1-e^{-\rho X_1})$$

the actual amount of technology transfer, and

$$D \equiv a X_2$$

the level of independent domestic research diminished by the extent to which the technology as a whole is not adapted to the environment.

As E_f increases, $-a^1/a$ is also increasing and X_j'/X_j is falling. The additional amounts of technology which become available with successive diminishments in the standards of adaptation be-become lower and ultimately are zero.

We may rewrite Z, holding T* fixed, as

$$Z = T^*(1-e^{-\rho X_1}) + D$$

and compare the marginal costs of acquiring additional technology via transfer or domestic

$$= \frac{C_1' e^{\rho X_1}}{\rho T^*} = \frac{C_1' e^{\rho X_1}}{\rho a^* t^* X_j} \qquad (9)$$

when technology is acquired through additional adaptive research, and

$$dC/dZ = \frac{dC}{dX_2} \cdot \frac{dX_2}{dZ}$$

$$= C_2'/a^* \qquad (10)$$

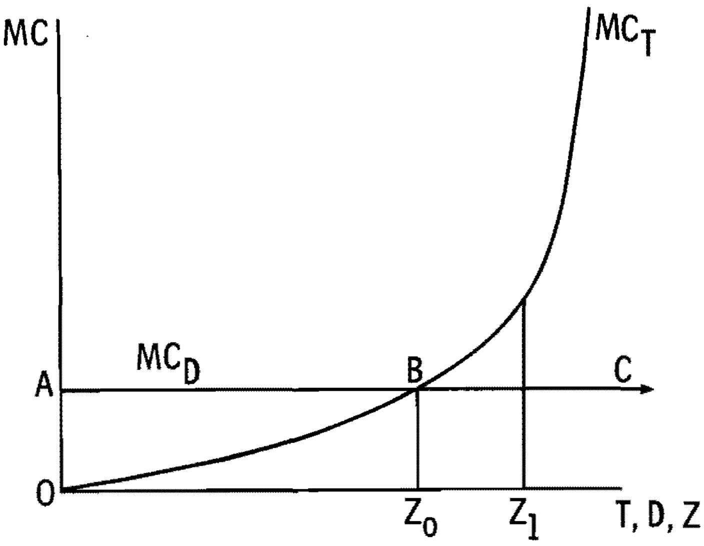
when technology is acquired through domestic research. The equilibrium condition for an interior solution required that the marginal cost of additional technology be the same, whether acquired domestically or through transfer. Thus,

$$\frac{C_1' e^{\rho X_1}}{\rho T^*} = \frac{C_2'}{a^*} .$$

whereas the marginal cost of domestic research is constant, once the level of a* (and therefore, t*, X_j*, T*, etc.) is fixed, the marginal cost of transfered research increases exponentially. Figure 5 shows the marginal costs of different levels of transferred and domestic research. It is clear that if the total amount of technology which is required is less than Z_0, transfered research will be relied upon to provide all of the technology. Any technology beyond Z_0 will be acquired domestically. For example, if Z is required Z_0 will be transfered and $(Z_1 - Z_0)$ provided from domestic sources. Because of this, the curve 0 B C is the marginal cost of research as a whole, and one could erase the portion of MC_T above B and the portion AB of MC_D and consider the remaining curve 0 B C alone.

It will be recalled that the above discussion had fixed the level of a* and, thereby, of T*. From the expression for the marginal cost of research acquired via transfer it can be seen that as T* increases (and a* falls) the marginal cost of transfered research will also fall. From the expression for the marginal cost of research acquired domestically, it is clear that the marginal cost of research acquired domestically rises as a* falls. From the relationship between T* and a*, it is clear that T* rises more slowly with successive decrements to the value of a*. These relationships are incorporated into Figure 6, which graphs the marginal cost functions at various levels of a*.

Note that a_0 a_1 a_2 a_3. The figure illustrates a tradeoff between the cost and potential of transfering research and the cost of domestic research. If g_1^1 is introduced as the marginal benefits function, one can see that there is an



equilibrium corresponding to each value of a^*, and that different totals of technology will be acquired at different levels of a^*. The maximization problem is

$$\max_{a^*} \left\{ \int^{MC_a{}^* \quad g_1'} (g_1' - MC_{a^*})\, dZ \right\}$$

From the drawing, it is clear that if we restrict the available values of a to the four presented, the intersection of MC_3 and g_1' presents the greatest net benefit level.

If marginal benefits shift out to g_2', similar inspection will show the intersection of MC_0 and g_2' as providing the most benefits. When g_3' is the marginal benefits curve, the preferred value of a is not clear, although the intersection of MC_1 or MC_2 and g_3' appear most likely. With g_4' as the benefits curve, the intersection with MC_0 appears to be the optimal point.

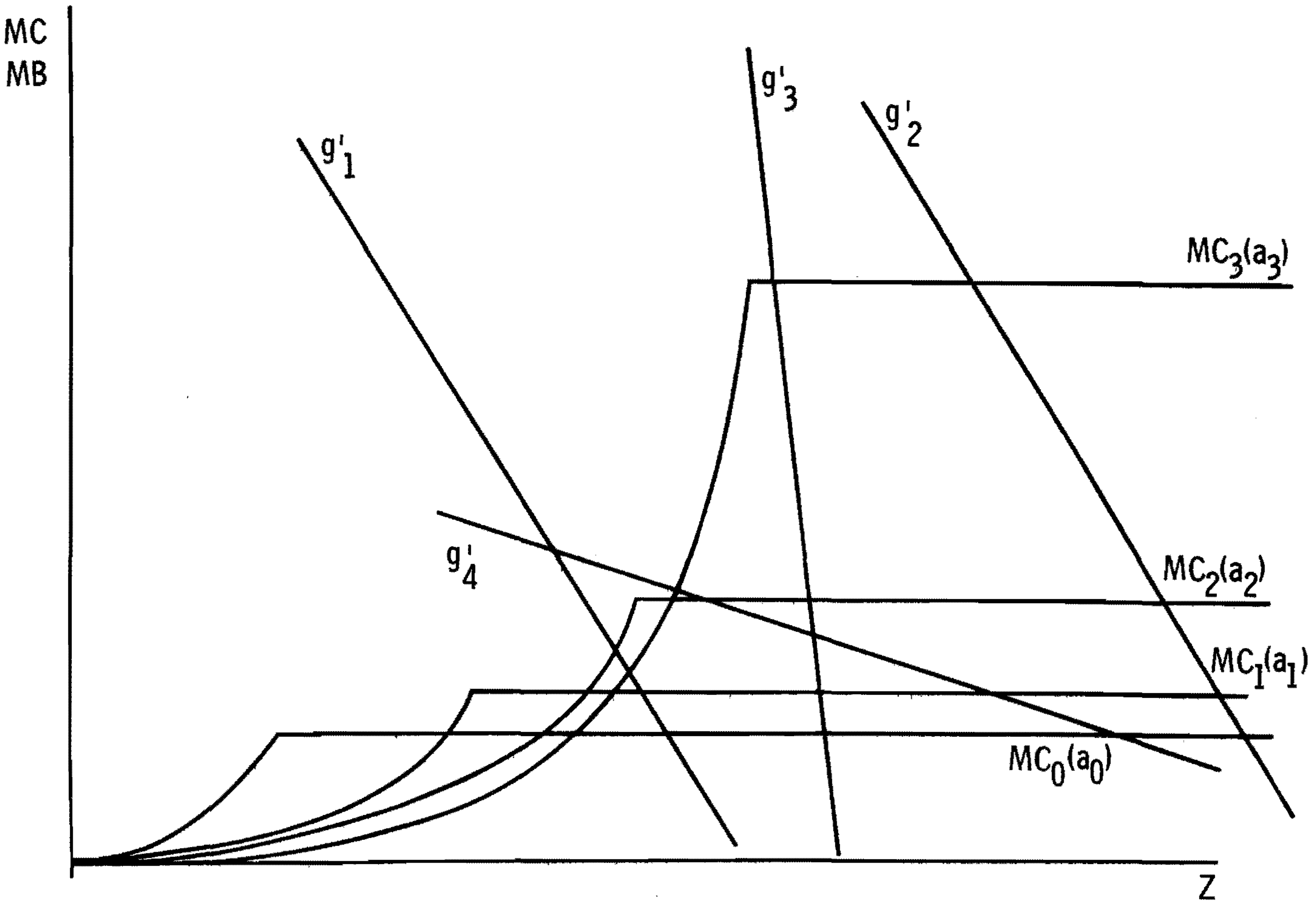
Several generalizations emerge. First, when marginal benefits are relatively low and falling rapidly, as with g_1', there will be a greater dependence on transferred research and a greater possibility of a corner solution in which all research is acquired through transfer. If this corner solution does emerge, then the optimal value of a will be that which is consistent with the maximum potential transfer, which will be lower than any value consistent with domestic technology generation.

Second, as the marginal benefits function shifts outward, there will be a tendency to rely more upon domestic research and less upon transferred research. This was illustrated by the choice of a higher value of a as the marginal benefits shifted from g_1' to g_2'.

Thirdly, as the marginal benefits function becomes more elastic, even at low marginal benefit levels as provided by g_4', there will be a greater tendency to rely on domestic research.

These generalizations suggest that as markets expand, there will be a tendency to shift from a pattern of reliance on adapted foreign research to research conducted locally and aimed specifically at the region. In fact, over time a region which initially adapted the technology of another region may come to be the primary source of new technology, the original source of new technology reverting to the role of adapter. Evenson has reported on shifts of the locus of inventive activity as measured by patenting of agricultural machinery in different regions of the United States at different times. These shifts appear to behave in rough conconcordance with the predictions of this model.

One might suspect that size of market is itself endogenous, depending on the success of the research venture at least to some extent. Such



interdependence is difficult to introduce into this type of model. One can envision a richer technology cycle model consisting of the following four stages. Evenson and Binswanger, have also outlined a technology development cycle.

The first stage would be direct transfer of technology into a different environment. This transfer may be a commercial experiment or a protected 'hothouse' endeavor.

In the second stage, various adaptive efforts would be incorporated into the technology.

The third stage would consist of evaluating the potential of the technology for further improvement. In many cases, this would amount to deciding whether the technology was competitive in world markets or could be with more research. This third stage can be regarded as judging whether the technology is competitive in long-run Hecksher-Ohlin terms. One can imagine that there exists a variety of long-run isoquant maps corresponding to various allocations of engineering and scientific resources. It is on the basis of these isoquant maps that the third stage decisions would be made.

In effect, the third stage would predict the scale at which improvements are to be evaluated. Anticipation of great success would increase the scale and, as shown before, lead to a greater emphasis of independent technology development.

The fourth stage implements the third stage decision. If the current or potential technology is found to be competitive, additional resources will be expended on the technology with a high likelihood that there will be a greater dependence on domestically produced, specific world seems littered with debris from industrial and agricultural projects which, proving unviable in competitive markets, produce for a domestic market, and display little or no productivity growth over time. On the other hand, the emerging success in certain activities, leather and textiles especially, indicates that the transition to the dynamic fourth stage can be accomplished.

As mentioned before, the recognition of mutual availability and usefulness of research by countries in the same environment can be regarded as lowering research costs. As a benchmark case, the effects of a simultaneous reduction in the costs of adaptive and independent research will be considered. In general, the result is similar to that of an outward shift of the marginal benefits function. However, there is a condition which must be fulfilled,

$$(e^{\rho X_1} - 1) > (\alpha - 1)\ \xi\ (g')$$

where

$$\alpha = C_2'/C_1'$$

and $\xi\ (g')$ is the elasticity of the marginal benefits curve. The intuitive explanation is that the marginal cost of acquiring additional technology varies inversely with the degree of adaptation to the domestic environment. As the cost of domestic research rises relative to the cost of adaptive research, there will be a greater tendency to use adaptive research so that a large percentage of potentially transferable technology will be acquired. However, this limits the potential for further acquisition via adaptation with price declines, so high values of C_2'/C_1' will encourage more use of domestic research with price declines.

The elasticity of marginal benefits enters into the condition because highly elastic marginal benefits favor domestic research, for the reasons discussed above. In general the condition would seem to be fulfilled.

This would suggest that if there are many little countries clustered in the same environment, lack of coordination in their research programs may encourage a greater dependence on adaptive research than would be efficient. Although the best solution would appear to be an increase in cooperation and information flows, this may be difficult to achieve in practice. A second best solution might be a "forced" increase in the amount of technology directed at the environment via establishment of an international center. This increase would encourage independent research in those environments in more similar environments.

This reasoning provides a justification for the establishment of international centers which does not rely on increasing returns to scale in a research. It is difficult to measure the range over which increasing returns exist, although plausible reasons have been suggested to support their existence.

The results suggest that establishment of regional research centers, which pool the resources of countries in similar environments, may be the best policy. It also suggests that centers which focus on many crops for a single environmental niche may be better than centers which focus on a single crop for many environments (although one ought to recognize that the niches will generally differ from crop to crop). Certainly, they seem to imply that while efficiency gains may be achieved by initially providing a stimulus to development of indigenously oriented research, beyond some point one ought to expect national programs to carry on the bulk of research. The long-run strategy would best consist of improving the research capacity of national systems and establishing research centers in environments possessing low stocks of research tailored to their needs.

Investment in Research and Physical Capital

The assumption of a fixed, unchangeable domestic environment may be too restrictive. There are possibilities for changing an environment, investment in irrigation being an obvious example, although there are others. If this is the case, the problem should be restated to allow for the addition of the domestic environment as a choice variable.

Two polar cases will be of interest. The first case we will examine is one in which it is easier to irrigate a smaller percentage of a region's area to a large extent than to irrigate a larger fraction of the area to a lesser degree. Certain dam projects which benefit relatively small areas would fall into this category. More generally, if there are high fixed costs to introducing irrigation, there will be an incentive to limit the area of irrigation. For the sake of simplicity, it will be assumed that an irrigated region will have free access to all of the technology created elsewhere for irrigated regions.

The maximization problem of the first section can now be rewritten as

$$\max \left[(1 - \alpha)\alpha g_0\ (Z) + g_1\ (X_I) - C_1(X_1, X_2) - \alpha^{\theta} C_I\right]$$

of the region, θ is a scale parameter, $\theta > 1$, reflecting increasing marginal costs to irrigating a larger percentage of a region, $g_1(X_I)$ are the benefits accruing to an irrigated piece of land

$$(X_I = \bar{X}_I),$$

and

$g_o(Z)$ is the research benefits function used throughout the earlier discussion.

Differentiating with respect to α, one obtains

$$\alpha^{\theta - 1} = (g_1 - g_o)/C_2$$

If we choose a value for α, say α', the rest of the maximization problem is almost exactly the same as the problem outlined in the first section. The crucial difference is that benefits are being spread over a smaller area, lowering the marginal benefits function in proportion to the reduction. In the previous section, it was seen that this would have two effects, a reduction in the total of acquired technology and a shift towards greater emphasis on transfered technology.

In (11), however, the value of g_o dependes on the level of (Z), and lower values of g_o induce higher values of Z. Whether the maximization problem presented has an interior solution will depend on whether or not the costs of extending irrigation rise faster than the marginal benefit to research falls. Otherwise the solution may be complete irrigation of the region or none.

If the interior solution does exist, we have seen that the unirrigated portion of the region will have less research and depend on transferred research to a greater extent. This may have serious consequences for inter-regional equity, the more so if the irrigated portion competes for resources with the unirrigated portion and is perceived as having greater potential.

The second case allows for irrigation benefits to be distributed over any area without increasing marginal costs. In fact, it will be assumed that the entire region is covered to the same degree by the irrigation network, and that the amount of the irrigation coverage in the region is itself a choice variable. If water control is thought of as a continuum from desert to completely and intensively irrigated, there can be many gradations in the degree of water control which can be introduced.

If we allow the subscript k to denote the extent of irrigation introduced, the maximization problem may be written as

$$(X_1, X_2) - C_2 (E_{Dh})$$

where $C_2 (E_{Dh})$ is the cost of shifting the domestic environment to environment h through irrigation.

The equilibrium conditions are similar to those which emerged earlier in equations (5) - (8)

$$\frac{a'}{a} = \eta \frac{t'}{t} = -\eta \frac{X_j'}{X_j} = -\frac{C_2'}{Z} \qquad (12)$$

where Z as always is the total of acquired technology (the argument of the g(.) function) and

$$g' \, a\rho t e^{-\rho X_1} X_j = C_1^1 \qquad (13)$$

$$g' \, a = C_1^2 \qquad (14)$$

The equilibrium conditions in (12) - (14) differ from those of (5) - (8) only in the last equality of (12). The interpretation is straightforward. The last inequality serves to set the marginal value of the easier adaptation of irrigated technologies equal to the marginal cost of more extensive irrigation. The benefit obtained from irrigation in this model is that it brings the domestic environment closer to those environments in which most of the technology has been developed resulting in greater ease of adaptation of research. Looked at a little differently, it serves to allow the region to avoid difficult problems which have not been solved elsewhere by physically altering the environment.

In general, the capital investment in irrigation facilities and the investment in research appear to be substitutes, the investment in irrigation inducing a lower demand for research. One could construct isobenefit curves with investment in irrigation on one axis and research investment on the second. Convexity of these curves guarantees a unique equilibrium. The equilibrium which would emerge will depend on the relative prices of irrigation and the two research activities and would be effected by shifts in these prices. One interesting possibility is that irrigation may be the preferred investment if labor costs are low and if there is an efficient, labor-intensive construction technique. It would be especially attractive if the laborers were drawn from a pool of unemployed or underemployed workers. Hayami has suggested that such considerations played a role in the development of the Japanese irrigation network.

While this result is suggestive, it is subject to many caveats. Firstly, the currently observed range of relative costs may not be sufficiently wide as to induce major substitution between one approach and the others. More important are the abstractions required to fit reality into static models. Irrigation without additional research would produce once and for all gains, while research holds the promise of a stream of improvements over time. As well irrigation may improve research productivity by eliminating drought resistance as a necessary component of the research agenda, making other goals more easily attainable. Finally, in most developing countries the cost of research can be lowered substantially in the long run by investing in the training of native researchers and developing a viable indigenous research system. There seemsless promise for the development of cheaper, labor-intensive construction techniques. One might wish, therefore, to use a lower relative price of research than is actually observed.

Measurement and Testing

One can proceed to test whether the results predicted by the model have real world counterparts. We saw that the nature of the 'appropriate' technology would be such that:

(a) as the price of adaptive research rose relative to independent research, there would be more emphasis on independent research.

(b) as the scale increased, there would be more emphasis on independent research.

(c) the degree of adaptation to the domestic environment and the relative importance of independent research would be positively correlated.

(d) as transferability increases, so would the emphasis on adaptive research.

(e) as the technology available from different regions increases, so would the dependence on transfer.

One must find measures or proxies for the levels of adaptive and applied research, the degree of adaptation, the degree of transferability, and the costs of domestic and applied research. It is possible in many research programs to obtain estimates of the numbers of foreign varieties tested in the varioustrials as well as the number of foreign parents used in breeding programs. If there is no reason for foreign material to be more costly in these types of experiments, we can compute the costs of adaptive research as the cost of the foreign material used in breeding and varietal trails. It seems reasonable also to assign the costs of more fundamental research entirely to the domestic portion of the program.

Let C_T be the cost of the various trials comparing varieties, C_B be the cost of the breeding program, and C_S be the cost of research on fundamental agricultural science.

Then if

α is the percentage of foreign varieties used in trials

and β is the percentage of foreign parents in the breeding program, we can set

$$V_1 = \alpha C_T + \beta C_B$$

and

$$V_2 = (1 - \alpha) C_T + (1 - \beta) C_B + C_S$$

to give us the amounts expended on adaptive and indepdent research.

If (a) - (e) are correct, we could estimate a regression equation

$$\frac{V_1}{V_2} = a_0 + a_1 R_1 + a_2 \frac{Z_f}{Z} + a_3 Q + a_4 \, W_S/W_T + a_5 \, W_S/W_C + \text{interaction terms}$$

where R_1 is a measure of transferability of research from other regions into the domestic region,

Z_f/Z is the ratio of foreign research to domestic research,

Q is a measure of the scale of production in the domestic region,

W_S/W_T is the cost of agricultural science research relative to yield trials, and

W_S/W_C is the cost of agricultural science research relative to breeding research.

There is some looseness in the definition provided above in terms of applicability to situations with more than two regions. In the latter case, both R and Z_f would have to be indeces of transferability and foreign research activity. The latter would have to be constructed with the recognition that an increase in research in a region with a high degree of transferability will have a greater effect than a similar increase in a region with a very different environment. Similarly, if, for some reason, transferability should shift, it makes some difference if the shift occurs in a region with a tiny research establishment or one with a larger research endowment.

Some candidates for the two-location transferability measure are (a) the simple rank correlation of yields of a set of varieties across two locations and (b) the correlation of the location by variety interaction effects of a set of varieties across two locations. The first measure has the disadvantage in that it may be tween the two locations.

Whichever measure is selected, in computing an index of overall transferability, some weighing scheme must be used. The best candidate is some measure of research inputs in the region producing the research for transfer. This could be expenditures, scientist-years, publications or some other suitable measure.

As we saw, the scale of operations itself would affect the distribution of effort between independent and adaptive research. Thus, the total production of the region or the land area should be used to represent the scale.

We also saw that the level of independent research would increase with the degree of adaptation of the technology to the environment.

If we let Y_F be the yield of varieties produced abroad and Y_D be the yield of varieties produced independently, then we would expect that Y_D Y_F would be positively correlated with V_2/V_1. Moreover, one could expect that even the varieties developed from crosses with foreign varieties would be positively correlated with V_2/V_1. This follows from the result obtained above that the research would tend to be more adapted to the specific location as the importance of independent research increased.

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THE DECLINING PRODUCTIVITY OF AGRICULTURAL RESEARCH

Jeffrey S. Davis and Willis Peterson*

Based on the results of numerous evaluations, agricultural research has gained the reputation of being a high payoff investment. Marginal internal rates of return in the neighborhood of 35 to 50% have been frequently reported.1/ While the returns to past investment in agricultural research appear to have been high, we should not use these figures to predict the payoff to current and future investment unless we can be reasonably sure that (1) the agricultural research production function is stable, *i.e.*, does not shift in a stochastic fashion from year to year, and (2) there is no pronounced trend in the productivity of agricultural scientists. The main purpose of this paper is to test these two propositions.

In regard to the stability question, the level of aggregation is crucial. Because of the large amount of uncertainty involved with the research process, we would expect the research production function to be highly unstable or stochastic at the individual project level. On the average, one or two projects out of 10 may produce significant results with the remainder yielding little or no new knowledge. Part of the differences in payoff between projects, may be due to sheer luck, but in large part is likely to be due to differences in the abilities of scientists, particularly in the ability to ask the "right questions."

We would argue therefore that *ex ante* evaluation of individual projects will not yield reliable results. The returns to the successful projects are likely to be severely underestimated while the returns to the "dry holes" will be grossly exaggerated. Moreover, it may not be evident even after a project is completed and written up whether it is a success, a failure, or something in between. Thus, the stability of a research production function is only a meaningful question when many projects are aggregated. One would expect greater stability moving from the department, to the experiment station, to the national level. We will measure stability at the station level.

Turning to the second hypothesis, one can think of reasons why the productivity of agricultural scientists might have decreased over the past 40 to 50 years, and other reasons why it might not have decreased. But before discussing these reasons, it is necessary to define research productivity. In this paper, we will measure research productivity by the coefficient on the research variable in an aggregate agricultural production function of the Cobb-Douglas form. This is the percentage change in agricultural output for a 1% change in research input. One could also measure research productivity by the VMP of research, or its associated rate of return in constant prices. However, these measures will be influenced by the value of agricultural output relative to research inputs (average product of research), and consequently can be affected by the amount of conventional resources allocated to agricultural production as well as by the productivity of scientists.

Discovery of nature's most accessible secrets by early research inquiries and the subsequent increase in difficulty and cost of producing additional increments to the known stock of knowledge is perhaps the most obvious reason for expecting a decrease in research productivity. If the potential stock of knowledge relating to agriculture is finite and other inputs are held constant, then agricultural research must eventually run into diminishing returns. Of course, no one knows if the potential stock of knowledge if finite. But the main reason why one might not be surprised by at least a constant productivity of scientific effort over the years is the large increase in the stock of knowledge that exists today in comparison to preceding decades. Because of the large increase in the stock of human and nonhuman capital (computers, better microscopes, *etc.*) the productivity of scientists could conceivably increase.2/

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elasticity of research, differences in model specification and data used make it impossible to compare results and to draw conclusions about the stability of the research production function or changes in the productivity of scientific effort over time.3/ In this paper, we will present the results of estimating six aggregate agricultural production functions with agricultural research and extension as separate variables from cross section data covering the census years 1949 through 1974. Major emphasis will be on the size and stability of the research coefficient over time.

I. The Model and Variables

We employ the basic Cobb-Douglas production function that has been used in most production function estimates of the returns to agricultural research.

$$(1) \quad Q = A \prod_{i=1}^{n} X_i^{\alpha_i} \prod_{\ell=1}^{m} R_\ell^{\beta_\ell} e^u$$

where:

- Q is the aggregate agricultural output per farm
- A is a constant shift factor
- X_i are the i = 1 to n conventional inputs
- R_ℓ are the unconventional inputs, mainly, research and extension expenditures
- α_i and β_ℓ are the coefficients of the respective inputs
- u is the random error term

A detailed description of the variables, their construction, and data sources is given in the Appendix. We present here a general description of the variables and the motivation underlying their construction. The main objective was to construct the variables in a manner that provided as much comparability as possible over the 25-year period. All the conventional variables and extension are measured on a per-farm basis whereas research is specified on a per-state basis. (We explain below why research is handled differently.) Forty states are included in the analysis.4/

A. Output

Output is defined as the sum of cash receipts from marketings, value of home consumption, government payments, and net change in inventories. Each of the 12 commodity groups making up the cash receipts from marketing figures was deflated by the corresponding USDA prices received index, 1967 = 100, before aggregating.

The conventional inputs include land, labor, machinery, fertilizer, and other inputs. Land and labor are adjusted for quality differences both cross sectionally and over time. Special attention is given to avoiding the capitalization of research benefits into the land variable. Land prices in 1944 are used as weights thereby eliminating any impact of technical change on the price of farmland since that time. As described in the Appendix, we also adjust labor for quality differences between states and over time.

Specification of the machinery variable probably causes more problems than of any other variable in models of this type. The main source of these problems is lack of information on the age of the various types of machinery on farms and how service flow varies with age. For example, old tractors tend to be kept mainly for light work. If these machines are valued at new prices, their service flow would be overstated. On the other hand, if they are valued at their depreciated or current market prices, the result will be to likely understate their service flow.5/ Because of these problems, expenditures on fuel and repairs are used as a proxy for the service flow of farm machinery. Admittedly, this procedure rules out the estimation of the VMP of farm machinery, but the strong likelihood of a high correlation between deflated expenditures on fuel and repairs and the true service flow of farm machinery should lessen the chance of biasing the research coefficient.

C. Weather

Because of differences in weather patterns between years and the possibility that such differences could influence the research coefficient, it is necessary to include a weather variable. Looking at weather in more detail, it is useful to separate the influence of weather into a location and a time effect. The first effect is associated with the geographical location of agricultural production. If long-run weather patterns have not changed appreciably over time, the location effect should be captured in the value of farmland. For example, land in the Corn Belt is in part more valuable than land in the High Plains because the former receives more rain than the latter. The second effect results from year-to-year variability in weather for a given location. While the degree of variability of weather is likely to be reflected in the value of farmland, the specific weather conditions prevailing in any given year will not be reflected by land values. To incorporate the time effect of weather, we include in the production function the USDA index of pasture conditions (as a percent of normal) in August of each of the six years. The variable should reflect

D. Research and Extension

Specification of the research and extension variable(s) in previous studies has shown considerable variability. Several aspects are important and require brief consideration here:

1) Should research and extension be combined?

In previous studies, the most common approach has been to add the two variables implying either fixed proportions or perfect substitution between research and extension. The two variables have been specified separately in cases where extension is included in a broader education variable. For the purpose of this study, it seems most reasonable to enter the two separately. The extreme assumptions of fixed proportions and perfect substitutes both seem implausible. And, in line with the objectives of this study, we do not wish to allow any changes in the coefficient on extension to distort the measure of research productivity, and vice versa.

2) Per-farm or per-state research and extension?

Past production function studies have utilized both per-farm and per-state specifications of the research variable. The criteria for selecting one specification over the other would seem to be that of public versus private goods. It seems reasonable to classify the output of publicly funded agricultural research as a public good. In general, the use of the results of this research by one person does not preclude use by others. As a result, the number of farmers in a given state should not have any bearing on the impact of that state's research on agricultural production of a given farm. Moreover, the deflating of total state research by number of farms could distort the measure of research output. For example, halving the number of farms should not double the VMP of research which would occur if research is specified on a per-farm basis. In addition, it has been empirically verified that per-state research is a better explanatory variable than the per-farm measure (Bredahl and Peterson, 1976). For these reasons, we adopt the per-state specification of the research variable.

In the case of extension, one can argue that the output of extension agents is a private good with externalities. In many circumstances the use of an extension agent's time by one farmer does preclude its use by others. While it is easy to think of exceptions to this situation, in general the private good nature of extension seems most applicable for production-oriented extension work. Therefore, we specify extension on a per-farm basis.

between the time research money is spent and the results show up as increased production. However, there is less certainty regarding the appropriate form of the lag and its duration. In order to test the sensitivity of the research coefficient to various lag structures, we estimated the production functions with the following research variables: current year expenditure, expenditure in t-6, the average expenditure in t-2 and t-6, and a 14-year constrained second order polynomial lag model. Surprisingly, we found relatively little difference in the size of the research coefficient under the various specifications of the research variable (Davis, 1980b). Therefore, we report the results only for the (t-2 + t-6)/2 specification; it is a simple lag yet fairly realistic. The question of the correct lag appears to be more important for computing rates of return to investment in research because of the discounting phenomenon.

II. The Main Results

Maddala (1977) has argued that for testing whether estimated coefficients have changed between data sets, it is more appropriate to use an F test on the results from the pooled versus unpooled data rather than "t" tests on individual slope dummy coefficients.6/ Moreover, if it is appropriate to pool the data, then the reliability of the coefficients will be improved.

In comparing the results from the six separate regressions with regression from the pooled data, we found that the set of coefficients did in fact change over the 1949-74 period.7/ However, when pooled estimates from shorter subperiods are compared to the individual year results, there is evidence of some stability. Specifically, the set of coefficients from the 1949-59 regressions are not statistically different from each other; the same is true for the 1964-74 period.8/ But there is a significant difference between the set of coefficients of the two subperiods. We present in Table 1 the results of the pooled regressions for each of the two subperiods.

The decline in the size of the research coefficient from .072 to .034 between the 1949-59 and 1964-74 periods is the most significant finding of the study. While there appears to be some stability in the agricultural research production function over 10- to 15-year periods in that the research coefficients are not statistically different within each of the two periods, there is a rather pronounced downward trend in the size of the coefficient during the past 25 to 30 years. A clearer picture of this trend might be obtained from the individual year research coefficients (and standard errors) presented in Table 2. (These figures are from the

Constant	-4.697 (.841)	-2.068 (.526)
Labor x Education	.562 (.075)	.330 (.056)
Fertilizer	.048 (.014)	.197 (.025)
Other	.318 (.036)	.356 (.033)
Machinery	.186 (.040)	.340 (.045)
Land	.137 (.024)	.037 (.021)
Weather	.122 (.044)	.058 (.061)
Research	.072 (.019)	.034 (.020)
Extension	-.058 (.029)	-.081 (.024)
Dummy 1954	.118 (.033)	
Dummy 1959	.263 (.059)	
Dummy 1969		.080 (.039)
Dummy 1974		.196 (.031)
$\bar{R}^2$	.977	.975
R.S.S.	1.18947	1.08769

*Figures in parentheses are standard errors.

corresponding individual year regressions presented in Table 1 in pooled form.)

Not only is there a downward trend over the greater part of the period, but the rate of decline accelerates from 1949 to 1969. Moreover, the 1964 through 1974 coefficients are not statistically different from zero at the standard confidence levels. The increase in the size and significance of the 1974 coefficient is noteworthy but one observation does not, of course, indicate a trend.

The obvious question at this point is, why has the research coefficient declined over the years? While it is beyond the scope of this study to offer a definitive answer to this question, one can think of a number of possible explanations.

1. Even though we have been careful to measure the inputs in units of constant quality and include all relevant variables, one cannot rule out the possibility that the model is still mis-specified and the coefficient on research is biased. For example, it is not clear if the omission of private R&D as an explicit variable causes a bias. We can be reasonably certain that the prices paid by farmers for purchased inputs contain a return to private R&D, so in this sense private R&D is implicitly included in the production function. If, for some reason, the research coefficient is biased, the question then becomes, Is the bias positive in the early years of the period, negative in the later years, or both? And if the research coefficient is biased, why should it be biased in part of the period and not in the other, or biased in different directions in different years?

2. Research results are becoming more pervasive and as a result it is becoming more and more difficult to capture the impact of experiment station research with cross-section data. For this explanation to carry much weight, one must think of a good reason why research results are becoming more pervasive over time.

3. Immediately after World War II there was a stock of known but unused technology "on the shelf" and by the end of the 1950s this technology had been widely adopted. If so, then the smaller, more recent year coefficients represent the true output of experiment stations.

4. Research productivity is cyclical in nature. As scientists exhaust lines of inquiry, their productivity declines until new breakthroughs occur. Then a new cycle begins.

Table 2: Individual Year Research Coefficients (and standard errors)

Year	Coef.	S. E.
1949	.070	(.034)
1954	.062	(.030)
1959	.044	(.024)
1964	.029	(.032)
1969	.014	(.032)
1974	.039	(.040)

5. Agricultural scientists have discovered nature's most accessible secrets and now must devote greater amounts of time and resources to produce additional increments of knowledge.

6. The number of undergraduate students per teaching and research faculty member in colleges of agriculture nearly doubled between 1959 and 1974, growing from about 4.7 students per faculty member in 1959-60 to 8.5 students in 1974-75.9/ If undergraduate teaching is competitive with research as seems reasonable, then research has subsidized teaching by increasing amounts over the period, particularly the 1960s and 1970s. Consequently, the measured amount of resources allocated to research is likely to overstate the true figure by larger and larger amounts over the period. It is possible that the true productivity of research may not have decreased at all.

7. Diseconomies of scale exist in experiment stations. As stations increase in size more of the research time of scientists is taken up by committee assignments and administrative duties resulting in less research output per dollar of expenditure.

8. The unexplained residual from the production function, which is what the research and extension variables are supposed to pick up, may have been caused by disequilibrium in the factor markets. A gap between the VMPs of purchased inputs, mainly chemicals, fertilizer, and machinery, and their respective prices can cause an unexplained residual in the production function. If the per-farm use of these inputs in the early part of the period was largest in the major agricultural states where agricultural research also was highest, we would observe a positive correlation between research and the residual. As farmers increased the use of these inputs and moved closer to equilibrium towards the latter part of the period, the unexplained residual decreased, leaving less for research to explain. A disturbing implication of this argument is that the correlation between state experiment station research and the residual was spurious to the extent that the lower real (quality adjusted) prices of these inputs, or the emergence of completely new inputs such as herbicides and insecticides, mainly were the result of private R&D.

The problem that we face is not a lack of an explanation for the observed decline in the research coefficient but rather one of too many explanations.

Another puzzle is the highly significant negative coefficients on the extension variable. One possible explanation for this result is that the higher the extension expenditures, the closer farmers are to equilibrium, and the smaller is

research have not created as many new disequilibria resulting from new inputs or techniques, and as a result their output is smaller than it would otherwise be.

Clearly, we have much to learn not only about the research production function itself but also about how research results are disseminated and how they affect output.

IV. Average and Marginal Products, and Rates of Return

The declining productivity of scientists as measured by the decrease in the production elasticity of research does not necessarily imply a corresponding decline in the rate of return to investment in research. Conversely, a stable coefficient does not imply a constant VMP or rate of return. Recall that in a Cobb-Douglas production function the marginal product of an input is given by the production elasticity of that input times its average product (units of output per unit of input). Also, because of the lag between research and the resulting output of agricultural products, the VMP of research must be discounted in order to convert it into a rate of return.

In Table 3, we present average and marginal products and marginal internal rates of return to public investment in agricultural research for the six years included in the analysis. To remove the effects of inflation but to allow for changes in relative product prices, the output values were deflated by the WPI before computing the average and marginal products.10/ Over the period, dollars of agricultural output per dollar of research declined by more than one-half, with most of the decline occurring in the 1950s and early 1960s. In more recent years, the downward trend of the average product of research appears to have stopped. Larger reductions in the VMP and rate of return is observed because of the decline in both the coefficient and average product. In spite of the decline, marginal rates of return to investment in agricultural research remain highly attractive--probably more than twice as high as the rate of return to more conventional investment. Of course, we should not lament the decline in rates of return; this is what should happen when more resources are allocated to high payoff investment.

Research in the United States*

Year	Average Product	Marginal Product	Rate of Return
1949	$557	$37.87	100%
1954	415	28.10	79
1959	317	21.09	66
1964	267	8.95	37
1969	255	8.58	37
1974	255	8.66	37

*The coefficients for computing each year's VMP were derived from a constrained quadratic polynomial lag model with an inverted 14-year lag. The sum of the partial research coefficients utilized for the 1949-59 period is .068 and .034 for 1964-74. The VMPs and rates of return should be interpreted as the change in the specified year's output resulting from the preceding 14 years of research. Consequently, the average product figures are the mean values of the corresponding 14-year period. See Davis (1980a) for further discussion of this procedure and for alternative methods of calculating rates of return.

Footnotes

1/For literature reviews on the returns to agricultural research, see Peterson (1971), Peterson and Hayami (1977), and Evenson, Waggoner, and Ruttan (1979).

2/The cost of computer services, etc. is included in the research input but new technology has reduced the real cost of these services over the years.

3/A detailed review of past studies revealed a range of research coefficient estimates of -.017 to .097 in aggregate agricultural production functions. See Davis (1979).

4/States excluded are the six New England states plus Delaware and Maryland. In comparison to the rest of the country, agricultural production in these states is relatively small and their agricultural research has shifted towards environmental and consumer issues.

5/Because an old tractor has a smaller number of years of useful life remaining than a new one, its market value (the estimated discounted present value of future return) will be smaller than the newer model even if the current year service flow of the two are the same.

$$F = \frac{(RSS - \sum_{L=1}^{N} RSS_i)/(NK - K)}{\sum_{L=1}^{N} RSS_i/(NT - NK)}$$

which has an F distribution with (NK - K) and (NT - NK) degrees of freedom.

where: RSS is the pooled function residual sum of squares.

RSS_i is the i^{th} individual cross-section residual sum of squares.

N is the number of cross-sections pooled.

K is the number of variables.

T is the number of observations in each cross-section.

7/The resulting F value for all six cross-sections is 2.82 with 40 and 192 degrees of freedom, whereas the critical F values are 1.39 and 1.59 at the 5% and 1% levels, respectively.

8/The F statistic for the 1949-59 period is 1.33 and 1.61 for 1964-1974. The critical F values with 16 and 96 degrees of freedom and 1.75 and 2.19 at the 5% and 1% levels respectively.

9/Undergraduate enrollments for 1959-60 and 1974-75 are 33,800 and 81,736, respectively. Number of teaching and research personnel for these years are 7,201 and 9,577, respectively. Undergraduate student enrollment figures are from the National Association of State Universities and Land Grant Colleges, annual convention proceedings, and number of teaching and research personnel in colleges of agriculture are determined by a head count of the personnel listed in Professional Workers in State Agricultural Experiment Stations, USDA Agric. Handbook Series.

10/As explained in section I, the various products making up gross output were deflated by their respective USDA price indexes for the purpose of estimating the production function in order to make the production function a physical relationship between inputs and output. Research expenditures were deflated by the index of professors salaries because the VMP of an input should be calculated from the value of output and the physical quantity of the input.

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Appendix

Output

The 12 commodity groups include meat animals, dairy products, poultry and eggs, other livestock, food grains, feed crops and hay, cotton, tobacco, oil crops, vegetables, fruits, and other miscellaneous commodities. Data on commodity sales, net change in inventories, government payments, and value of home consumption are from various issues of Farm Income Statistics and Farm Income-State Estimates. The price indexes for deflating the commodity groups are from the USDA Annual Price Summary, 1975. To deflate home consumption, government payments, and the change in inventories, a composite price index was constructed for each state for each cross section by weighting the price index for each commodity group by its proportion of the total receipts from marketings. Data on number of farms in each state is taken from the various issues of the Census of Agriculture.

Land

The land variable was constructed by first multiplying the acreage of land in each state in each land category for each of the six years (taken from various issues of the Census of Agriculture) by Hoover's (1961) price weights, where an acre of pasture is given a weight of 1.0. The number of pasture equivalent acres in each state in each year was then multiplied by the 1944 value of an acre of pasture land to obtain a dollar value of land of constant quality between states and over time. This procedure should avoid picking up any capitalization of research benefits into the value of land since 1944.

Labor

To construct labor, we employ the same procedure utilized by Griliches (1964) using data from the various issues of the Census of Agriculture. This gives a measure of total number of farm operator equivalent days worked on farms in each state. The labor variable was then multiplied by an education variable to yield a constant quality labor input between states and over time. The education variable was constructed by multiplying the proportion of the rural farm males over the age of 25 in the various years of schooling completed categories by the corresponding mean income level for each category. The resulting weighted average income figures are ed from the 1960 Population Census while the mean income figures for each schooling category are from Houthakker (1959).

Machinery

As mentioned, expenditures on fuel and repairs are used as a proxy for the service flow of farm machinery. The USDA index of motor supplies was used to deflate repairs while a price index constructed from the prices paid by farmers for diesel fuel was used to deflate the fuel component. (Data sources are the USDA Annual Price Summary (1975) and various issues of Agricultural Statistics.)

Fertilizer

This input is defined as expenditures on fertilizer and lime deflated by the USDA index of fertilizer prices. The expenditure data is from various issues of State Farm Income Statistics, and Farm Income-State Estimates, and the price index is from the USDA Annual Price Summary, 1975. A fertilizer variable made up of the weighted average of plant nutrients, using prices as weights, also was constructed. However, there is considerable variation in relative prices of plant nutrients over the period which makes it difficult to determine the "correct" weights to use. Also the two alternative fertilizer variables gave similar results.

Other Inputs

This category includes feed and livestock purchased, as well as expenditures on seed, repairs to farm structures, and other miscellaneous inputs such as pesticides, medicines, and custom work. Each item was deflated by the appropriate USDA prices paid index before aggregating.

Weather

As mentioned, this is the USDA index of August pasture conditions where "normal" conditions in each state is assigned an index of 100. The index is taken from various issues of Crop Production.

Research

This variable is defined as total expenditures of the state agricultural experiment stations minus expenditures on land and buildings. Data from 1934 to 1961 are from Latimer (1964) and from 1962 onward from the various issues of Funds for Research at State Agricultural Experiment Stations and other Cooperating Institutions. A price index constructed from average salaries of college and university teachers was used to deflate research expenditures (Davis, 1979).

to 1961 are from Latimer (1964) and for the remaining years from unpublished tables circulated to all agricultural experiment stations. The total extension expenditure figures were adjusted to reflect only production oriented extension (adjustment factors from Cline, 1975). The adjustment factors and producer oriented extension are reproduced in Davis (1979). The research price index described above was used to deflate extension.

THE PRODUCTIVITY AND ALLOCATION OF RESEARCH: U.S. AGRICULTURAL EXPERIMENT STATIONS, REVISITED

George W. Norton*

Estimates of marginal products and rates of return to cash grains, dairy, poultry, and other livestock research in the United States were made by Bredahl and Peterson using 1969 Census of Agriculture data. Their results showed national returns to crop and livestock research to be in the 36 to 46% range. These estimates of returns, several times higher than market rates, have proven useful to agricultural researchers and administrators in supporting budget requests. Bredahl and Peterson provided marginal products by commodity groups by states which have been used by economists in particular states to calculate rates of return to research on commodity groups in those states (Mitchell, Coffey, Babb, and Pratt). More recently, Davis has 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. Stability in the aggregate, however, does not necessarily imply stability over time across commodity groups or states. Stability of the research coefficient is an important issue since estimates from studies such as Bredahl and Peterson's are used in making projections of returns to future research spending. Instability over time would indicate that one should not make projections which make use of research coefficients from only one cross-section.

The main focus of this paper, therefore, is to provide additional evidence on the efficiency of allocation of research resources among commodity groups and regions within the United States. Data from the 1969 and 1974 Censuses of Agriculture are employed in aggregate agricultural commodity group production functions to test if the research coefficient for any or all of these groups has remained stable from 1969 to 1974. A second purpose of the study is to examine the effects on the research coefficients of certain variables not tested in the Bredahl and Peterson study. Variables are included to account for research spillover, weather differences, and land quality differences across states. Alternative research lags are tested and the importance of the assumed research lag on the rates of return is also illustrated. The question of research spillover is an important one and has recently received increased attention in the literature (Evenson, White and Havlicek, Davis, Garren and White). It is really the lag in spillover or the incomplete spillover of research results from one state to another that allows one to pick up any variance with a state level research variable in a cross-sectional production function. The spillover that occurs, if unaccounted for, will likely bias the state marginal products derived from commodity group production functions.1/

The Model

The basic model used in the analysis is a familiar cross-sectional Cobb-Douglas production function with conventional inputs specific to individual commodity groups and corresponding research expenditures included as independent variables:

$$(1)\quad Y_t = A \prod_{i=1}^{m} X_{it}^{\beta_{it}} R_{t-j}^{\alpha_{t-j}} S_{t-j}^{\gamma_{t-j}} e^{u}$$

where: Y_t is the value of commodity group output; A, a shift factor; X_{it}, the ith conventional production input in year t; R_{t-j}, the expenditure on research per state in year t-j; S_{t-j}, the expenditure on research in other states affecting each state; β_{it}, the production coefficient of the ith conventional input in year t; α_{t-j}, the production coefficient of research in the t-jth year; γ_{t-j}, the production coefficient of spillover research in the t-jth year; u, a random error term.

Bredahl and Peterson used current (1969) rather than lagged research expenditures as the research variable. While this affected the

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estimated input coefficients provided that research has been increasing at a constant rate over time such that $R_{t-1} = KR_t$ when $0 < K < 1$. Other studies have assumed a lag of six to seven years. Davis found that the value of the research coefficient was not sensitive to the specification of the research lag. In this paper, a simple average of research expenditures in 1967-69 was used in most of the estimated production functions. The sensitivity of the research coefficient to lagging the research variable to 1967, 1968, 1969, and 1974 was also tested and is described later in the paper.

The Variables and Data

All variables in the four commodity group functions are measured on a per-farm basis except research and research spillover where state and neighboring state total research expenditures are used to reflect the "public good" nature of research. The major sources of data for nonresearch variables were the 1969 and 1974 Census of Agriculture (U.S. Dept. of Commerce, 1972, 1973, 1977) and unpublished data used by Bredahl and Peterson. Price deflators were obtained from various USDA publications. State experiment station research expenditures were obtained from selected volumes of the Inventory of Agricultural Research (USDA, 1969-70, 1974) and unpublished computer printouts (USDA, 1967, 1968). Specific definitions of the variables can be found in the Appendix. Two of the variables, weather and research spillover, not included in the Bredahl and Peterson study are discussed below.

It is difficult to construct an appropriate weather variable because a combination of crops with varying rainfall and temperature requirements are included in the cash grains group. An attempt was made, however, to capture the effect of deviations from normal weather for a particular location by including deviations from normal July rainfall in that commodity group function.2/ Differences in climate due to difference in location are accounted for in one of the estimated cash grains functions by including dummy variables for different cropping regions.

Bredahl and Peterson mentioned the likelihood of research results from one state spilling over into other states biasing the marginal product. Evenson (1979) and Davis have attempted to account for the spillover in aggregate agricultural production functions by dividing the county up into geoclimatic regions and arriving at subjective proportions of the regional research applicable to each state.

Any approach used to measure the degree of research spillover (including neglecting it entirely) clearly involves arbitrary judgments on how much regional research to include in each state's several individual commodities the research for which spills over in different directions and amounts. Soybeans, for example, are very sensitive to day-length and as a result varietal spillover is oriented in an east-west direction. Regional adoption of wheat varieties follows a very different pattern.

The approach taken in the present study to account for research spillovers uses the 16 geoclimatic regions found in Evenson (1979). In most cases, these regions do not follow state boundaries. Research expenditures are prorated among the subregions within each state using its distribution of the commodity group output as a basis. The measured research spillover from state i into neighboring state j consists of the research that occurred in production region k in state i multiplied by the fraction of state j's research which also occurred in production region k. Most states have several of these types of research spill-ins which are then totaled to make up its research variable.

This procedure is admittedly crude and probably underestimates the spillover effects in most cases. It may underestimate the spillover for dairy, poultry, and other livestock more than cash grains because the former is less dependent on climate and soils. The distance over which substantial research borrowing occurs is probably greater for a commodity such as broilers than it is for one such as corn.

Regression Results

The regression results obtained by duplicating Bredahl and Peterson's equations using 1969 data are presented in equation 1 in Tables 1-4.3/4/ Equation 2 in each case represents the same functions estimated with 1974 data. For the most part, the regression coefficients have reasonably large t-values. Of particular interest are the research coefficients which exhibit a wider range for the 1974 data set than for the 1969 data. The research coefficients for cash grains, dairy, and livestock are all slightly larger and more significant than 1969 counterparts. Poultry, on the other hand, is much smaller but no longer significant.

These measured differences between the two sets of equations are not necessarily statistically significant. Therefore, covariance analysis was used to test (1) if each production function as a whole was stable over the period and (2) whether the research coefficient was statistically stable over the period. The estimated regressions in which the 1969 and 1974 data were pooled are shown in equation 3 in Tables 1-4. In each pooled equation the intercepts were allowed to vary to take account of the fact that the lag in the research variable

	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
1. Land and buildings	.142 (1.59)	.217 (2.20)	.222 (3.64)	.221 (3.59)	.243 (2.38)
2. Labor	.241 (2.90)	.356 (2.41)	.267 (3.94)	.264 (3.88)	.347 (2.34)
3. Chemicals	.089 (2.06)	.011 (.25)	.044 (1.77)	.042 (1.64)	-.001 (-.03)
4. Seed	.11 (1.35)	.196 (2.42)	.195 (4.01)	.202 (3.99)	.216 (.67)
5. Fertilizer	.053 (1.04)	.061 (.64)	.023 (.56)	.021 (.52)	.423 (2.39)
6. Machinery	.540 (3.36)	.476 (2.84)	.469 (4.31)	.468 (4.28)	.105 (3.64)
7. Research (67-69 average)		.091 (3.68)			
8. Research (69)	.073 (2.72)				
9. Research (pooled)			.082 (4.88)	.070 (2.40)	
10. Intercept Dummy for 69 & 74			.295 (4.21)	.077 (.18)	
11. Research Slope Dummy for 69 & 74				.017 (.52)	
12. Research Spillover					-.034 (-.96)
13. Constant	.479 (.76)	-.085 (-.082)	.162 (.32)	.322 (.55)	.504 (.42)
$\bar{R}^2$	.929	.932	.952	.951	

*Numbers in parentheses are t-values.

differed in the 1969 and 1974 data sets. The value of the computed F-ratios for the cash grains, dairy, and poultry equations were above their critical values in the F-table for their corresponding degrees of freedom.5/ This indicates that these data sets should not be pooled because there have been some structural changes over time. The F-ratio for livestock was below its critical value in the table indicating a lack of structural change.

These results do not tell us whether the research coefficient is stable over time but only whether the coefficients as a group are stable for each commodity group. A t-test can be used to test the stability of the research coefficient alone by including a slope dummy on the research variable. Equation 4 in Tables 1-4 shows these results. In all cases, we cannot reject the hypothesis that the research coefficients are the same at the 95% level of significance. In the cash grains, dairy, and livestock cases, this result is not surprising since the coefficients for the two years are of the same magnitude. In the poultry case, the nonsignificance of the research coefficient apparently does not

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land and buildings	.062	.084	.081	.078	.085
	(2.82)	(2.88)	(4.19)	(4.02)	(2.83)
2. Labor	.547	.227	.390	.386	.223
	(8.28)	(2.53)	(7.66)	(7.57)	(2.37)
3. Cows	.204	.427	.333	.329	.428
	(3.28)	(4.90	(6.04)	(5.97)	(4.85)
4. Feed	.210	.277	.245	.253	.280
	(4.17)	(5.25)	(7.78)	(7.78)	(5.04)
5. Pasture	.055	-.041	.006	.008	-.040
	(2.29)	(-1.50)	(.27)	(.36)	(-1.50)
6. Research (67-69 Average)		.057			
		(3.12)			
7. Research (69)	041				
	(2.62)				
8. Research (Pooled)			.044	.031	
			(3.68)	(1.89)	
9. Intercept Dummy for 69 & 74			.336	.032	
			(15.97)	(.12)	
10. Research Slope Dummy for 69 & 74				.024	
				(1.13)	
11. Research Spillover					.004
					(.196)
12. Constant	1.32	5.47	1.80	1.96	2.99
	(2.95)	(9.56)	(4.31)	(4.44)	(4.09)
$\bar{R}^2$	.986	.978	.983	.983	.978

*Numbers in parentheses are t-values.

allow us to pick up a statistically significant difference for the two periods.

There are at least two possible explanations for the nonsignificance of the research variable in the 1974 poultry equation. The first is that the spillover of poultry research across state boundaries is very important and that states with a low amount of research have borrowed from neighboring states to the point that their poultry sector is just as productive. It is really the lag in borrowing research from other states, regions, etc., or the incomplete borrowing that allows one to measure a return to research in cross-sectional studies. Also, if the rate of progress in poultry technology has slowed, this would facilitate lower research states catching up with higher research states. Poultry research, in particular, is transferable over a long distance. A second explanation is due to the fact that broilers, turkeys, and eggs are combined in the data set. In some states the proportion of egg production approaches 100% of the poultry output. Egg prices were relatively higher than turkeys in 1974 compared to 1969 so that those states with a higher proportion of egg production experienced a larger percentage increase in value of output than those with a high proportion of turkey output. This could be affecting to some extent the research

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land	.145	.078	.120	.119	.098
	(4.05)	(2.30)	(4.99)	(4.89)	(2.66)
2. Labor	.163	.190	.159	.163	.196
	(2.37)	(2.47)	(1.25)	(3.29)	(2.56)
3. Poultry	.261	.180	.214	.226	.175
	(2.62)	(2.32)	(3.64)	(3.61)	(2.26)
4. Feed	.591	.700	.668	.653	.702
	(5.38)	(7.93)	(10.64)	(9.53)	(8.02)
5. Research (67-69 Average)		.017			.022
		(.52)			(.649)
6. Research (69)	.071				
	(1.84)				
7. Research (Pooled)			.041	.048	
			(1.77)	(1.81)	
8. Intercept Dummy for 69 & 74			.001	.268	
			(.014)	(.56)	
9. Research Slope Dummy for 69 & 74				-.021	
				(-.56)	
10. Research Spillover					.025
					(1.31)
11. Constant	-1.09	-.232	-.786	-.842	-.84
	(-1.79)	(-.35)	(-1.89)	(-1.95)	(-1.05)
$\bar{R}^2$	.916	.931	.958	.958	.933

*Numbers in parentheses are t-values.

coefficients for 1974.

The results of including a spillover variable in an equation for each of the commodity groups is presented in equation 5 in Tables 1-4. In none of the equations was the spillover variable significant. This result undoubtedly reflects more on the crude nature of the spillover variable specification than it does on the importance of research spillover. Other attempts were made to include a research spillover variable in each commodity group equation but these were also unsuccessful.

The three parts of the poultry output variable were also deflated to remove the price effects from combining poultry, eggs, and turkeys. This affected the equation very little.

A number of other tests were made using the 1974 data for all the commodity groups. The CRIS research data include categories labeled "unclassified" research, "unallotted plant science," and "unallotted animal science." Since these categories are large for some states, research variables were constructed which included a portion of this unclassified and unallotted research. The coefficients on these new research variables differed little from those which did not include the unclassified and unallotted research.

The effect of using lagged versus current research expenditures as the research variable was discussed earlier. Alternative research lags were tested in the 1974 commodity group equations as well as the use of current research, but

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land and buildings	.129	.042	.126	.115	.068
	(1.53)	(.51)	(2.32)	(2.10)	(.65)
2. Labor	.554	.517	.469	.516	.465
	(1.94)	(2.46)	(2.88)	(3.09)	(2.07)
3. Animals	.136	.057	.114	.100	.068
	(1.16)	(.56)	(1.50)	(1.31)	(.65)
4. Feed	.320	.465	.376	.380	.462
	(2.38)	(5.02)	(4.93)	(4.99)	(-1.95)
5. Research (67-69 Average)		.168 (6.98)			.153 (4.68)
6. Research (69)	.122 (4.69)				
7. Research (Pooled)			.137 (8.01)	.122 (5.59)	
8. Intercept Dummy for 69 & 74			.062 (.71)	-.44 (-.999)	
9. Research Slope Dummy for 69 & 74				.040 (1.16)	
10. Research Spillover					.025 (.675)
11. Constant	-.455	-.24	-.366	-.237	-.299
	(-.511)	(-.264)	(-.584)	(-.374)	(-.327)
$\bar{R}^2$	.849	.908	.891	.891	.907

* Numbers in parentheses are t-values.

the resulting research coefficients were similar. There was, however, somewhat more variability in the research coefficient in the cash grains equation than in the other commodity group equations.6/

As noted earlier, deviations from normal in July rainfall was also included as a variable in the cash grains function, but the coefficient on that variable was not significant. This is not too surprising in light of the number of different grains included in the cash grains function. Slope dummies on the land variable were included to account for climatic and quality differences in land in the cash grains function, but they were not significant. In this case as well, the aggregation of several grains could be masking the effects of these factors.

The research coefficient was not sensitive to various weighting schemes used on the elements which make up the fertilizer variable. This was tested because previous studies have assumed a variety of weighting schemes and the validity of the one used by Bredahl and Peterson is open to some question.

Marginal Products and Rates of Return

The estimated research coefficients can be used to compute the marginal products of experiment station research. The computed national average marginal product of research for each commodity group is MPR = $\hat{\alpha}\bar{n}\left(\frac{\bar{Y}}{\bar{R}}\right)$ where $\bar{n}$ is the arithmetic average number of farms for that group, $\hat{\alpha}$ the corresponding research coefficient, and $\bar{Y}$ and $\bar{R}$ are the geometric mean levels of per-farm output and per-state research for that group.

The estimated marginal products of research computed with both the '69 and the '74 estimates are presented in Table 6 . 7/8/. These marginal

Table 5. Marginal Products for Experiment Station Research

	Marginal Products (in constant prices) 1969	1974
Cash Grains	24	42
Poultry	23	--
Dairy	20	27
Livestock	62	81

In his recent dissertation, Davis points out that previous authors have used varying formulas for computing the internal rate of return (IRR) to research. All have used the general procedure of finding the discount rate which satisfies: discounted (MPR) - 1 = 0. Differences stem, however, from the assumption made about the distribution of benefits over time. The most conservative assumption is that all benefits occur in the "n^{th}" year after the research expenditure. The formula for this is $\mathrm{MPR}/(1-r)^n - 1 = 0$, which can be rearranged to $r = (\mathrm{MPR})^{\frac{1}{n}} - 1$, where r is the marginal internal rate of return. As Davis points out, this formula can be very useful for approximation purposes because it is not necessary to use an iterative procedure to calculate the IRR. Bredahl and Peterson made use of the conclusions of Evenson that the best representation of the distribution of benefits over time is that of an inverted V. This can be represented by the shaded area in Figure 1.

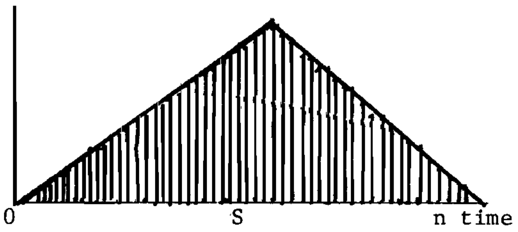

Figure 1.

Davis points out that the following equation can be used to calculate the marginal internal rate of return assuming the lag distribution used by Bredahl Peterson:

$$\mathrm{MPR}\left[\sum_{i=1}^{n} \frac{w_i}{(1+r)^i}\right] - 1 = 0$$

$$w_i = \frac{2n - (2i-1)}{2S^2} \quad \text{For } i = S + 1 \text{ to } n$$

n = total number of years over which past research has an impact on output.

$S = \frac{n}{2}$ is called the mean lag

r = marginal internal rate of return

MPR = marginal product of research

This formula was used to calculate the IRRs of research to the four commodity groups for both 1969 and 1974 under five different assumptions about the length of the research lag (see Table 6).9/

One of the conclusions that can be drawn from the IRRs in Table 6 is that they have increased over the five-year period for cash grains, livestock, and dairy. This is mostly due to the slightly higher coefficients on the research variable because the average products were deflated to make the marginal products reflect cash grain and livestock prices in 1969. Since the output variable is a price-weighted aggregate for each commodity group, the higher output prices in 1974 otherwise would have increased

Table 6. Internal Rates of Return to Experiment Station Research

	Assumed Mean Lag (Years)	Internal Rate of Return (%) 1969	1974
Cash Grains	5	57	85
	6	47	69
	7	40	58
	8	35	50
	9	31	44
Dairy	5	50	62
	6	42	51
	7	35	44
	8	31	38
	9	27	33
Livestock	5	111	132
	6	89	106
	7	75	88
	8	64	75
	9	56	66
Poultry	5	56	--
	6	46	--
	7	39	--
	8	34	--
	9	30	--

to research expenditure in 1974 as compared to 1969.

Bredahl and Peterson assumed a five-year lag for cash grains, a six-year lag for poultry and dairy, and a seven-year lag for other livestock. They concluded that the resulting IRRs indicated that agricultural experiment station research is being allocated fairly efficiently across the four categories. The results from Table 6 generally support this conclusion despite the changes made in the '69 data, which were discussed earlier. The livestock return is somewhat higher than the others, however, indicating the largest underinvestment in livestock research. The results for 1974, assuming the same set of lags, would lead one to conclude that returns to cash grains research has increased relative to dairy and other livestock. The results also illustrate very clearly the importance of the mean lag assumed between the time the research occurred and the results are realized. While this lag was shown not to be of great importance in the estimation of the research coefficient, it is extremely important in measuring the IRRs. For example if both cash grains and livestock had the same lag, the cash grains IRR would be below that for livestock for 1974. If livestock had a two year longer lag than cash grains, their IRRs would be about equal for 1974. If cash grains had a lag of five years and livestock a lag of eight years, the return to cash grains research is higher than for livestock in 1974.

Assuming the production elasticities do not differ among states, marginal products of research can be computed for each state for each commodity group by multiplying the research coefficient by the average product of research for each group. Those marginal products are shown in Table 7. They should be taken as very rough approximations since they take no account of the effect of research spillover across state boundaries. They appear to confirm the conclusions of Bredahl and Peterson that there are substantial differences across states for each group and that returns are highest in those states where the product makes up a large share of the agricultural output of the state. If one compares the marginal products in Table 6 with those in the Bredahl and Peterson article, no movement is detected toward an equalization (equilibrium) across states or across commodities within a state.

Conclusions

The research coefficients for cash grains, dairy, and livestock were shown to be statistically stable between the 1969 and 1974 census years while poultry was inconclusive. This lends some support to those studies which use coefficients from past research evaluation physical output is also quite important for the calculation of the internal rate of return. Finally, the results do not lend support to the belief that returns to agricultural research declined during the early '70s. The results for

Table 7. Marginal Products of Research by Commodity Groups by State, 1974.

State	Cash Grains	Dairy	Livestock
Alabama	8.6	5.23	19.97
Arizona	3.5	8.47	48.07
Arkansas	47.62	5.96	46.13
California	19.42	29.35	55.60
Colorado	51.00	74.01	146.71
Connecticut	.23	7.75	46.70
Delaware	4.88	1.62	14.98
Florida	4.88	12.65	15.46
Georgia	11.01	6.56	26.91
Idaho	27.23	25.89	79.73
Illinois	85.05	6.29	78.51
Indiana	35.75	11.43	53.94
Iowa	33.58	10.39	105.06
Kansas	33.58	6.45	136.47
Kentucky	33.28	14.57	33.79
Louisiana	37.20	3.39	6.46
Maine	16.77	7.27	12.23
Maryland	15.52	7.17	9.73
Massachusetts	.10	11.81	10.62
Michigan	24.75	10.68	32.65
Minnesota	34.15	34.43	166.58
Mississippi	17.36	11.98	39.98
Missouri	36.07	7.33	103.25
Montana	31.96	5.44	35.79
Nebraska	29.26	4.07	73.81
Nevada	1.55	4.30	22.65
New Hampshire	.02	9.21	24.56
New Jersey	5.25	4.46	4.55
New Mexico	12.85	21.50	130.93
New York	3.01	32.23	10.20
North Carolina	13.22	5.73	32.14
North Dakota	41.60	18.46	61.91
Ohio	41.94	17.29	39.66
Oklahoma	22.69	12.97	65.64
Oregon	13.99	8.28	30.56
Pennsylvania	9.55	20.76	37.98
Rhode Island	n.a.	1.85	4.41
South Carolina	10.95	4.92	12.94
South Dakota	20.45	18.28	92.44
Tennessee	18.71	5.75	19.08
Texas	38.99	41.11	197.25
Utah	6.27	8.46	51.71
Vermont	.35	18.27	5.64
Virginia	9.77	15.59	26.59
Washington	18.72	15.61	40.72
West Virginia	2.26	13.89	41.49
Wisconsin	9.59	56.69	30.53
Wyoming	8.94	2.64	37.11

roughly the same or increased. If the 1974 average products were not deflated to 1969 prices, the increases would be even greater.

Footnotes

1/Bredahl and Peterson recognized this and hypothesized that states with the largest departments or research areas are net exporters of research. This would have the effects of biasing the estimated marginal products of the small stations upward and marginal products of the large stations downward.

2/Weather was extremely variable during the summer of 1974. This might be expected to have a small effect on the dairy, poultry, and livestock functions but a more significant effect on cash grains. If good weather prevailed in states with high research expenditures and poor weather in states with low research expenditures this would bias the research coefficient upward. If the opposite occurred, a negative bias would result.

3/The dairy and poultry results are identical to those published by Bredahl and Peterson. Adjustments were made for three states in their cash grains research data and the fertilizer variable was specified differently causing the coefficients on that equation to differ slightly from the one they reported. Their data was not available for the livestock group and therefore, had to be regenerated from their original data sources.

4/Bredahl and Peterson presented instrumental variables as well as OLS estimates but since the differences were small only OLS results are presented in this paper.

5/The test used for homogeneity of slope coefficients was:

$$\frac{V'V - V^{*\prime}V^{*}/K-1}{V^{*\prime}V^{*}/n_1 + n_2 - 2K} = F_{k-1,\ n_1 + n_2 - 2K}$$

where: $V^{*\prime}V^{*}$ = vector of residuals from adding the sums of squared residuals from the 69 and to 74 functions
$V'V$ = vector of residuals from pooled regression
K = number of parameters including constant
n_1 = number of observations in 1969 function
n_2 = number of observations in 1974 function

were lower than when 1969 and 1974 research variables were used.

7/The average products ($\frac{\overline{Y}}{R}$) have been converted to 1969 dollars to facilitate comparisons between 1969 and 1974 marginal products.

8/A marginal product of research for 1974 for poultry was not calculated due to the nonsignificance of the research coefficient.

9/Following Bredahl and Peterson, to arrive at conservative estimates of rates of return, the marginal product figures in Table 5 were divided by three to take account of public extension and private research before calculating the IRRs.

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I. Cash Grains

Variable

1. Output Value of grain sold per farm.
2. Land Harvested cropland per farm.
3. Labor Man-days of operator, unpaid family, and hired labor per farm--Operator - The total man-days of operator labor is determined as follows:

$$L_o = (N_1 + .6N_2)\ .300 - L_1$$

where: L_o = man-days of operator on farm labor

N_1 = number of operators less than 65 years of age

N_2 = number of operators over 65 years of age

L_1 = man-days of off-farm labor

Unpaid family - Data on the hours worked per worker for farm operators, other unpaid family members, and all family workers for four weeks of the year are provided in the USDA publication Farm Labor, February 28, 1975, pages 6-7. These data are used to determine the percentage of farm operator hours which are worked by unpaid family labor. This percentage is then multiplied by the number of farm operators from the 1974 Ag. Census to get the number of unpaid family workers. This is then multiplied by the number of hours per week from the Farm Labor data and then converted to man-days per year.

Hired Labor - The value of hired and contract labor per farm from the census is divided by the state wage rate to get the number of hours of labor. This is then multiplied by 8 to get the number of man-days per year.

4. Seed Value of seed per farm.
5. Fertilizer Data on the tons used, dry and liquid, are found in the 1974 Ag. Census for each state. Data on the tons of N, P, and K applied per state is found in the USDA publication Commercial Fertilizer Annual Consumption for the Year Ended June 30, 1975. This last data is used to determine the amounts of N, P, and K represented by the total tons of fertilizer shown in the census. For example, if N is 40% of the total fertilizer applied in the USDA data, then the tons shown in the census data are multiplied by 40% to get the tons of N applied on the census farms. The value of N, P, and K per farm are aggregated together with weights of 1, 1, and .5, respectively.
6. Chemicals Value of agricultural chemicals (herbicides, insecticides, and fungicides) per farm. The census value for herbicides is deflated by the ratio of the national to the state

were undeflated. The three resulting values are added and divided by the number of farms.

7. Machinery Service flow of machinery plus expenditures for energy sources plus hired machinery and custom work - (1) The market value of machinery and equipment is divided by the number of farms multiplied by .15. (2) Data on gasoline, oil, and other petroleum fuels are given on page 1-82 of Vol. I of the 1974 Ag. Census for each state. The gasoline and diesel fuel components are deflated by the ratio of the national to the state price of these fuels. These data are found on page 115 of the USDA publication, Agricultural Prices, 1974. (3) Data on machine hire and custom work are found on page 1-82 of Vol. I of the 1974 Ag. Census for each state.

8. Research Total expenditure on research--Data are found in the USDA-CRIS publication Inventory of Agricultural Research FY 1969. For each state, the total expenditures for corn, sorghum, wheat, soybeans, barley, oats, rye, and other small grains are totaled.

9. Weather Deviations from normal July precipitation.

10. Soils dummies based on 1957 U.S. Yearbook of Agriculture Geoclimatic Regions.

II. Dairy

Variable

. Output Value of dairy products sold per farm nd dairy type livestock sold per farm. Sales ata are multiplied by an index which equals the ratio of the sales of the i^{th} product to total sales times a ratio of the national average to he state average price for the i^{th} product where i = fluid milk sales to plants, direct milk ales, and cream sales. The value of livestock urchased is subtracted from the value of livetock sold and added to the sales figure.

. Land Value of land and buildings per farm djusted by the ratio of national average price f land to state average price of land since we re mainly interested in how value of buildings ary.

. Labor See discussion under "Cash Grains" arms.

. Feed Value of feed expenditures per farm--ata on dollar value, number of farms, number of ons of each of four feed categories found is ound in the Ag. Census. The first category, ormula feeds, is adjusted by ratio of national-o-state price of 16% dairy feed. The second ategory, feed ingredients, is adjusted by ratio f the national-to-state price of soybean meal. he third category, whole grains, is adjusted by he ratio of the national-to-state price of corn. he fourth category, hay, green chop, and silage, s deflated by the ratio of the state-to-the-ational price of hay.

these are adjusted by the ratio of state-to-the-national average price for cows.

7. Research Total expenditures on research for the dairy category in the CRIS data.

III. Poultry

Variable

1. Output Value of poultry and poultry products sold per farm. Same type of adjustments as for dairy only items are broilers, turkeys, and eggs
2. Land See "Dairy" discussion.
3. Labor See discussion under "Cash Grains" farms.
4. Feed See discussion under "Dairy" farms.
5. Poultry Purchased Value per farm adjusted by ratio of national to state average price.
6. Research Total expenditures on Poultry research.

IV. Livestock Other Than Dairy, Poultry and Specialty

Variable

1. Output Data on number of cattle and calves sold, hogs and pigs sold, and number of sheep and lambs sold can be found in the Ag. Census. Data on value of production per animal is derived from the value of production, and number of animals sold data in Meat Animals, USDA publication. Multiplying the value of production per head by the Ag. Census data gives a value of output which takes out the double counting due to sale of feeder cattle, pigs, and sheep within the state.
2. Land See "Dairy" discussion.
3. Labor See discussion under "Cash Grains" farms.
4. Feed See discussion in "Dairy" section.
5. Livestock Number of breeding stock for beef cows, swine, and sheep times their value per head times .15 plus livestock purchased.
6. Research Research expenditures on Cattle, Swine, and Sheep and wool categories from CRIS data.

IMPORTANCE OF NEW VARIETIES IN KANSAS WHEAT PRODUCTION

Frank Orazem and Mark A. Jamison*

The preamble of NC-148 Regional Project stresses the need for more and better information as well as the analysis of the past and potential payoffs of publicly supported research programs, particularly those supported through agricultural experiment stations.

While no one questions the phenomenal productive capacity of American agriculture--much of which has been contributed by agricultural and related research--the public and its elected representatives are increasingly concerned about the "high public expenditures" and rightfully demand improved information on how well research expenditures pay off.

This study examines the effects of new varieties the last three decades (1948-78). Historically, Turkey Red was the dominant winter wheat variety in Kansas. At the turn of the century, virtually all Kansas wheat acres were seeded to Turkey Red--more than 82% in 1919 of the wheat acres used Turkey Red. The 82% had dropped to about 29% in 1939 and to 15% by 1945.

Since then, new varieties have replaced Turkey Red entirely. It disappeared from state reports before 1970. Newer wheat varieties have several advantages over the older varieties: smut and mildew resistance, hessian fly resistance, early maturity, stiff straw quality, etc. But the differences in yields are the most striking. Approximately the same acreage (13.5 million acres) produced 115 million bushels in 1939, 178 million in 1950, 345 million bushels in 1977, and more than 400 million in 1979.

The average wheat yield in Kansas in the 1930s was about 12 bushels per acre; in the 1940s, 15; in the 1950s, 19; in the 1960s, 24; and in the 1970s, 32 bushels per acre. Factors contributing to the increased yields include improvements in quality of seed; better tillage operations; better control of diseases, weeds, and insects; increased use of fertilizer; and improved management. Better adapted varieties probably have played the most important role in increasing yields.

Wheat Variety Comparisons

Using test-plot data from experiment station farms, we compared the new varieties with Turkey Red yields from 1949 to 1978. In total, 356 test plots grew Turkey Red during the period. We compared the 24 most commonly grown varieties the past 20 years with Turkey Red. Each time one of the new varieties appeared in a test plot with Turkey Red, receiving the same treatment, that variety's yield in bushels per acre was divided by the yield of Turkey Red. This was done for over 2,600 observations. The results of our calculations are in Table 1. In addition to the number of observations, we also determined the average ratios (wheat variety divided by Turkey Red, $\bar{X}_i$), standard deviation (S_i) and t-statistics (Table 1). For example, Apache variety outproduced Turkey Red on average of 13%, Bison by 20%, Centurk by 41%, etc.

Impact of New Varieties on Wheat Production

The variety planting distributions of yearly data make it possible to calculate expected annual yield changes that result from improved varieties.1/ Thus, it is possible to estimate what wheat production in any year would have been if Turkey Red had been the only variety grown.

Table 2 shows wheat yields statewide, as well as the estimated state yield with only Turkey Red; the wheat acreage and the wheat acreage that would have been needed to match the given year's state wheat output with only Turkey Red. For example, in 1978 the state yield was 30 bushels, with Turkey Red it would have been 23

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bushels or 7 bushels per acre less; wheat production that year was 309 million bushels from 10.3 million acres. On the same acreage with Turkey Red, the production would have been 237.6 million bushels or 71.4 million bushels less. To offset the 71.4 million-bushel loss, an additional 3.1 million acres planted to Turkey Red would have been needed. Similar comparisons are shown in Table 2 for 1959 through 1978.2/

The search for varieties that offer an improvement over the old established ones is an on-going process. It does not stop. It can be seen by examining year to year changes in leading wheat varieties.

Table 3 shows the leading wheat varieties with percentages of wheat acres planted in 1980. With the exception of two (Scout and Triumph), none of the other eight varieties planted in 1980 was available in 1970. Table 3, for example, also indicates the quick emergence of the 1980 leading variety, "Newton." In 1978 the Newton variety was planted on 0.1% of the 12.8 million acres sown in wheat in Kansas. In 1980, two years later, Newton has been planted on 2.25 million acres, 17.5% of the total. On the other hand, Scout, which in 1970 occupied nearly half of Kansas wheat acreage, by 1980 its percentage dropped to 12.5 sown acres.

Technological changes not only bring shifts in the use of varieties, but at times affect and alter the relative significance of crops produced in certain areas. Changing comparative advantages or disadvantages induce some crops to move into a new area while others may move out or decrease in importance.

An example of how technological development changes areas' competitive positions and thus have an important bearing on farm enterprises and

Table 1. Wheat varieties, variety/Turkey Red - average ratio, standard deviation, t-statistic, and number of observations

Wheat variety	Variety/Turkey Red average ratio	Standard deviation	t-statistic	Number of observations
	X_i	S_i	t_i*	n
Apache	1.1295	0.2954	1.6983	15
Bison	1.2015	0.2283	13.1485	222
Buckskin	1.3761	0.3107	8.4727	49
Centurk	1.4073	0.3055	12.7867	92
Chanute	1.2069	0.3253	4.8014	57
Comanche	1.1828	0.2337	11.2960	203
Eagle	1.3478	0.3542	9.4164	92
Gage	1.3009	0.3251	11.2960	149
Kaw	1.1785	0.3022	7.4731	160
Kiowa	1.1895	0.1985	9.3513	96
Lancer	1.2302	0.1428	9.8054	37
Larned	1.3910	0.3656	5.4536	26
Ottawa	1.2569	0.3442	8.0391	116
Parker	1.2857	0.3041	10.3335	121
Ponca	1.1605	0.2848	7.8689	195
Rodeo	1.2779	0.2824	10.0849	105
Sage	1.4347	0.3573	9.8103	65
Satanta	1.2084	0.2550	6.8390	70
Scout	1.2891	0.2780	14.4089	192
Tam-W-101	1.4236	0.5638	3.0978	17
Trison	1.3171	0.4166	5.7959	58
Triumph	1.1854	0.3552	9.0417	300
Wichita	1.1985	0.2862	10.4718	228

*The average yields of all varieties except Apache differ significantly from Turkey Red's yield. Apache (PL0.001) differs at between 0.05 and 0.10.

incomes is that of hybrid corn and hybrid sorghums. In the early 1930s Kansas produced about 3 million hogs and 3.5 million cattle a year. Then hybrid corn became available to feed hogs and cattle. Compared with Corn Belt states, Kansas at that time had relatively little corn acreage, so hybrid corn gave the Corn Belt states a competitive edge until the late 1950s, when hybrid sorghum became available. By then, Kansas was producing less than one-third as many hogs and about the same number of cattle as she had in the early 1930s. Many more people were eating much more meat per person and meat exports had risen. But Kansas was not getting even her depression share of the market. Hybrid corn had given the Corn Belt states a competitive advantage in finishing cattle and in feeding hogs.

Table 2. Index of wheat production, wheat acres and bushels and estimated bushels had Turkey Red wheat variety been seeded on all wheat acreage in Kansas, 1959-1978.

	Years									
	1978	1977	1976	1975	1974	1973	1972	1971	1970	1969
Index	1.3	1.3	1.288	1.275	1.249	1.241	1.236	1.240	1.236	1.229
Actual Yield-T	30	28.5	30	29	27.5	37	33.5	34.5	33	31
Yield-H	23.07	21.91	23.29	22.74	22.02	29.81	27.09	27.83	26.69	25.23
Diff(Yield)	6.93	6.59	6.71	6.26	5.48	7.19	6.41	6.67	6.31	5.77
Actual Bu-T(000)	309,000	344,850	339,000	350,900	319,000	384,800	314,900	312,605	299,013	305,319
Bu-H(000)	237,640	265,225	263,224	275,201	255,465	310,064	254,671	252,199	241,846	248,491
Diff(bushel) (000)	71,360	79,625	75,776	75,699	63,535	74,736	60,229	60,406	57,167	56,828
Actual Acres-T(000)	10,300	12,100	11,300	12,100	11,600	10,400	9,400	9,061	9,061	9,849
Acres-H(000)	13,392	15,732	14,552	15,428	14,484	12,906	11,623	11,231	11,202	12,101
Diff(Acres) (000)	3092	3632	3252	3328	2884	2506	2223	2170	2141	2252

	1968	1967	1966	1965	1964	1963	1962	1961	1960	1959
Index	1.217	1.206	1.193	1.189	1.169	1.184	1.164	1.165	1.161	1.176
Actual Yield-T	24.998	20	19.5	23.965	22.519	21.5	23.5	26.5	28	20
Yield-H	20.53	16.57	16.35	20.15	19.25	18.16	20.18	22.75	24.11	17
Diff(Yield)	4.468	3.43	3.15	3.815	3.269	3.34	3.32	3.75	3.89	3
Actual Bu-T(000)	243,755	221,620	200,070	243,264	215,640	185,480	211,171	273,718	290,640	209,700
Bu-H(000)	200,274	183,713	167,762	204,622	184,401	156,694	181,353	234,993	250,276	178,246
Diff(Bushel) (000)	43,481	37,907	32,308	38,642	31,239	28,786	29,818	38,725	40,364	31,454
Actual Acres-T(000)	9,751	11,081	10,260	10,151	9,576	8,627	8,986	10,329	10,380	10,485
Acres-H(000)	11,867	13,367	12,235	12,067	11,198	10,211	12,463	12,031	12,054	12,335
Diff(Acres) (000)	2116	2286	1975	1916	1622	1584	1477	1702	1674	1850

Wheat variety	Years			
	1980	1979	1978	1970
Newton	17.5	2.8	0.1	0
Eagle	15.7	21.1	23.0	0
Scout	12.5	15.6	19.6	48.1
Larned	11.1	8.4	2.8	0
Sage	8.8	12.7	14.0	0
Centurk	5.9	8.7	10.0	0
Triumph	5.1	6.5	5.8	11.7
Tam 101	4.8	4.9	4.1	0
Voma	2.9	0.8	0	0
Trison	1.8	1.8	2.0	0

That changed when hybrid sorghums became available. The first hybrid sorghum seed in Kansas was distributed commerically in 1957. By 1966, five counties produced more sorghum than all 105 Kansas counties produced in 1956, the year before hybrid seed became available. Within a few years, the sorghum producing areas of the Great Plains, called the "Milo Belt" by some, became a feed-surplus rather than a feed-deficit area.

In addition, since 1970, Kansas has had every January 1 nearly six times more cattle on feed than January 1, 1957. The increase in cattle feeding in Texas has been even more dramatic. Thus, the "Milo Belt" became a bona-fide competitor with the Corn Belt. In 1956, the Corn Belt fed nearly 50% of U.S. cattle and the Milo Belt, about 20%; now, 1980, the percentages are almost even. The number of cattle fed in the Corn Belt has not decreased. But nearly all the tremendous gains in beef feeding in recent years has been in the Great Plains area--Texas, Oklahoma, Kansas, Colorado, New Mexico and Nebraska.

None of the changes came overnight, but they came with such rapidity that the packing industry, the grain trade, transportation, and other allied industries have had difficulty adjusting to them.

APPENDIX

(1). Calculation of the average ratio of Wheat Variety/Turkey Red, $\bar{X}_i$

$$\bar{X}_i = \frac{\sum_{j=1}^{n} \frac{Xij}{TRj}}{n}$$

where i denotes a wheat variety, j denotes test plot observation; thus, Xij is the yield of wheat variety i in test plot j, TRj is the respective Turkey Red yield in test plot j, and n denotes the number of observations.

(2). The standard deviation (S_i) is obtained by:

$$S_i = \frac{\sum_{j=1}^{n} \frac{Xij}{TRj} - \bar{X}_i^{2}}{n-1}$$

(3). The t-statistic is calculated by:

$$t_i = \frac{\bar{X}i - 1}{S_i / \sqrt{n}}$$

(4). Wheat production index (Table 2) is obtained by:

$$\sum_{i=1}^{n} \bar{X}_i D_{it} = \text{Index}$$

Where $\bar{X}_i$ is defined as above in (1), t denotes the year, D_{it} denotes the percentage of total wheat acres in Kansas planted to variety i, n is the number of varieties planted to more than 1% of the acres in year t. The relatively small acreage planted to insignificant varieties was

Footnotes

[1] Derivation of Wheat Production Index is explained in the Appendix.

[2] Statistical analysis (regression) using state yields of wheat as dependent variable and wheat production index as independent variable was highly significant. The coefficient of determination (R^2) of about 0.9 suggests that the derived crop index is a good indicator of the wheat yields of varieties grown in the years considered.

THE ECONOMIC IMPACT OF INVESTMENT IN INTEGRATED PEST MANAGEMENT

A. A. Araji*

Introduction

Following World War II, pest control largely shifted from a biological discipline to a chemical one. Unilateral dependence on pesticides has also resulted in concentrating effort on developing high-yield crop varieties with disregard for loss of characters for tolerance or resistance to pests. The broad ecological dictum of considering the whole interacting system was generally ignored and, thus, the importance of natural enemies and the plant's own factor for resisting pests. Excessive reliance on pesticides for the last three decades has destroyed natural enemies and caused some pests to develop resistance to pesticides. Consequently, the use of frequent treatments with increasing dosages was adopted in an effort to control pests. This development, however, increased production costs of many crops without alleviating the problem (Huffaker and Smith).

The rise of energy and pesticide costs combined with growing ecological and social concern about excessive pesticide use have encouraged scientific and public attention to initiate coordinated research on agricultural pests that consider the biological, cultural, and ecological aspects of controlling pests. The United States International Biological Program (IBP) initiated in 1971 with the cooperation of the National Science Foundation, the Environmental Protection Agency, and the U.S. Department of Agriculture, and 18 land-grant universities has set the foundation for the development and implementation of coordinated pest control programs which are more efficient and less harmful to public health and the environment.

Direct techniques and methods of control utilized in integrated pest management (IPM) include: crop plant resistance, biological control, cultural control, pesticide use, attractants and repellants, and growth regulation. In addition to the direct pest control methods, collecting the necessary information by monitoring or sampling the pest population and its principal natural enemies at appropriate times of the year is required for effective management decisions. Through monitoring and short-term weather prediction it was possible in 1976 to reduce insecticide treatments of cotton from 10 to two applications per year (Huffaker and Smith). In general, IPM uses the best combination of all known control techniques and concentrates on the plants themselves rather than the pests.

Relevant Literature

Economic analysis of pest control has emphasized the timing and application of pesticides. Headley defined the economic threshold within the framework of a single pest population growth model and a single application of pesticides. Hall and Norgaard studied the optimal timing and pesticide application. Smith showed that pests exposed to intensive pesticide application will develop resistance, and thus optimal pest control should take pest resistance into consideration. Taylor and Headley considered pest resistance in the optimal control of pest population. Hueth and Regev investigated the effect of increasing pest resistance to insecticides on the optimal control of a pest population by constructing a single-pest, single-crop management model. Talpaz et. al. estimated optimal pesticide application for controlling the boll weevil on cotton, Rumker, et. al. evaluated 19 cotton pest management programs, three peanut pest management programs, and three tobacco pest management programs in the United States. The programs were evaluated in regard to costs, effect on crop yield, pesticide use, production costs, and grower's profits. The environmental impact and the biological and economic feasibility of each program were analyzed.

Implementation of IPM programs on 3,600 acres of cotton in four areas of Texas (the lower Rio Grande Valley, South Texas, the Texas Blackland, and Trans-Pecos) in 1973 and 1974

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cotton yield. The implementation of the program increased net return per acre for participants by \$55.31 in the Rio Grande Valley, \$17.95 in the Blackland, and \$30.59 in the Trans-Pecos in 1973. A further increase in net return of \$15.73, \$18.89, and \$61.84 for these areas was noted in 1974 (Frisbie *et. al.*). Evaluation of integrated cotton pest management program in Texas for 1964-1974 shows that producer net return increased by \$7.33 and \$4.60 for each dollar of program costs for 1973 and 1974, respectively. The estimated effect of the program on production was an increased yield of 60 lbs. of lint per acre in 1973 and 36 lbs. per acre in 1974. Implementation of the program increased participant insecticide use by about 1 pound per acre in 1973 compared to a reduction of 2.25 lbs. per acre in 1974. For both 1973 and 1974, lint yield per pound of insecticide use was increased (Lacewell *et. al.*).

Objective of the Study

The primary objective of this study is to evaluate the economic impact of investments in integrated pest management research and extension programs by commodities in the United States. Specifically, the following objectives are sought: (1) to estimate the benefit-cost ratio of investment in IPM; (2) to estimate the internal rate of return to investment in IPM; (3) to estimate the reduction in pesticide use resulting from the implementation of IPM; and (4) to evaluate the extent of technology transfer between and within regions of the United States.

Method and Procedures

Two basic approaches have been used in evaluating agricultural research and extension: (1) the *ex post* approach, and (2) the *ex ante* approach. Most evaluation studies have used the *ex post* approach. *Ex ante* evaluation is based on the projected future benefits of research and extension. In this study, the *ex ante* approach was adopted to evaluate the economic impact of present and future investments in IPM programs.

Current and planned IPM programs in the United States were evaluated. A set of questionnaires was developed to assess present and future costs associated with each program for each commodity and the expected benefits from the implementation of the technical knowledge forthcoming from current and future research and extension programs. Personal interviews were conducted with researchers and extension specialists actually involved in the development and implementation of IPM programs in leading agricultural research and extension centers in the four regions of the United States in 1978. The following information was obtained for each project and and extension projects for each commodity; (2) the probability of research success; (3) the probability, time lag, and rate of adoption of research results with and without extension; (4) maximum expected adoption and the percentage of crop or livestock affected in each year of adoption; (5) research, extension, and private resources required to develop, implement, and maintain the new technology; (6) the expected elimination of active toxic material from the environment that would result from the implementation of the new technology; (7) the expected changes in yield, quality, and cost of production ensuing from the implementation of the new technology; and (8) the pattern of technology transfer within each region and between regions. In order to account for research and extension costs in supporting fields, all research and extension expenditures allocated to pest management programs in each commodity for the duration of the program were used to estimate the rates of return to investment.

The Model

The flow of benefits from each research project was estimated by the following equation:

$$(1)\quad B_{jt} = A_{jt}\,[(1+\Delta P_{jt})V_t - V_o - \Delta C_{jt}]$$

where: B_{jt} = benefits accruing to the jth technology in year t,

A_{jt} = expected total production affected by the jth technology in year t,

ΔP_{jt} = expected change in net productivity of the affected crop or livestock due to the jth new technology in period t,

V_t = expected price of each unit of output of the affected crop or livestock in year t, and $V_t = [V_o + V_o\,(f.\Delta P_t)]$ where f is the flexibility ratio, and V_o is price per unit in the base year,

V_o = price per unit of output in the base year,

ΔC_{jt} = expected change in production cost of the affected crop or livestock due to the jth new technology in year t.

B_{jt} is the maximum benefit that could accrue to society as a result of implementing the research findings. However, the outcome B_{jt} is probabilistic in nature because it depends on the proability of research success, P(S), and the probability of adoption, P(A). Thus, the expected flow of benefits from research and extension is defined as:

t=1

where N is the number of years for which the research technology, j, affects production and/or cost.

The present value of the expected flow of benefits from the research and extension investment is obtained by "discounting" the right-hand side of equation 2:

$$(3) \quad E(B_j) = \sum_{t=1}^{N} B_{jt} \cdot P(A_t \cap S_t)/(1+r)^t$$

where r is the social discount rate.

Similarly, the present value of the flow of the research and extension costs may be expressed as:

$$(4) \quad Z_j = \sum_{t=1}^{N} (M_{jt} = I_{jt} + E_{jt} + R_{jt})/(1+r)^t$$

where:

Z_j = the present value of the total costs associated with investment in, and implementation of, the jth technology,

M_{jt} = the costs of maintenance research required to sustain output at previously achieved levels for technology j,

I_{jt} = implementation costs incurred by the farmer in adopting the jth technology,

E_{jt} = extension costs involved in transferring the jth technology to the farmer, and

R_{jt} = annual expenditure for research investment for the jth new technology for the affected crop or livestock in year t.

The 1978 production year was used as the base year to calculate changes in productivity, cost, and price due to research and extension. Expenditures in each research problem area prior to 1978 were compounded at 6% to bring the costs to the 1978 level. All measures of benefit were calculated with and without extension to estimate the contribution of cooperative extension to research effectiveness.

Measures of Benefit

Several measures of benefit were calculated in this report. The benefit-cost ratio B/C is defined as the ratio of the present value of the expected flow of benefits from the implementation of research results to the present value of the flow of expenditures. This benefit-cost ratio is expressed as:

$$(5) \quad B/C = E(B_j)/Z_j$$

value of the expected flow of expenditures in the development, implementation, and maintenance of technology and the present value of the expected flow of benefits. The internal rate of return is calculated by an iterative process using the following equation:

$$(6) \quad E(B_j) - Z_j/(1+IRR)^t = 1$$

where:

IRR = internal rate of return.

The net present worth (N.P.W.) is defined as the present value of the expected flow of benefits $E(B_j)$ minus the present value of the flow of expenditures (Z_j). These measures of benefit were calculated for each research and extension problem area and aggregated by commodity, using a social discount rate of 10%.

Analysis of Results

The adoption profile, probability of adoption and probability of research success of integrated pest management were estimated for the commodities considered in this study. The adoption profile considers the year of adoption, adoption rate with and without extension involvement, probability of adoption, and probability of research success. For example, for alfalfa, the first expected year that research results will be adopted is 1983. Only 10% of alfalfa acreage is expected to adopt the research results with extension involvement. No adoption is expected without extension in the first year. An estimated 75% of the alfalfa acreage will adopt the research results with extension involvement in the fifth year compared to only 25% without extension. The extension role consists of conducting field trials to demonstrate the results, advising farmers of the adoption procedure, and demonstrating the immediate and future economic and environmental benefits of the program to individual farmers and society.

The probability of adopting the results of alfalfa IPM research was estimated at 90%. Probability of research success was estimated to range between a low of 80% to a high of 90%. The estimated probability of adoption and the lower probability of research success was applied to the annual rate of adoption to estimate the actual acreage of alfalfa that is expected to adopt the program annually.

Technology transfer from one area to another was evaluated (Figures 1-6). The results show that 60% of the alfalfa acreage in Arizona, 50% of the acreage in Oregon and Washington, 40% of the acreage in Idaho, and 30% of the acreage in

Figure 1. Technological Transfer from Integrated Pest Management Research: California, Alfalfa (——); Indiana, Alfalfa (—·—); New York, Alfalfa (- - -)

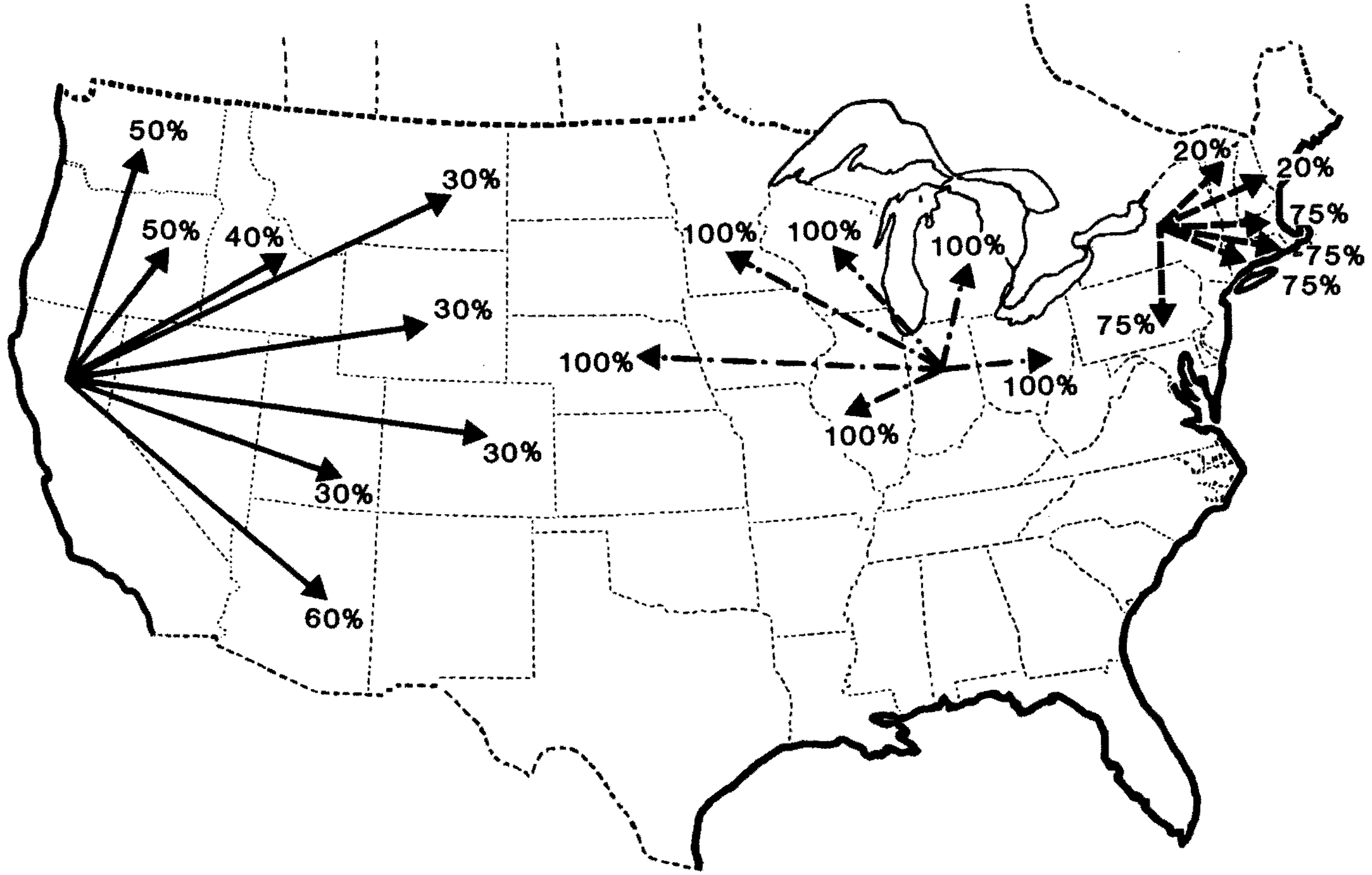
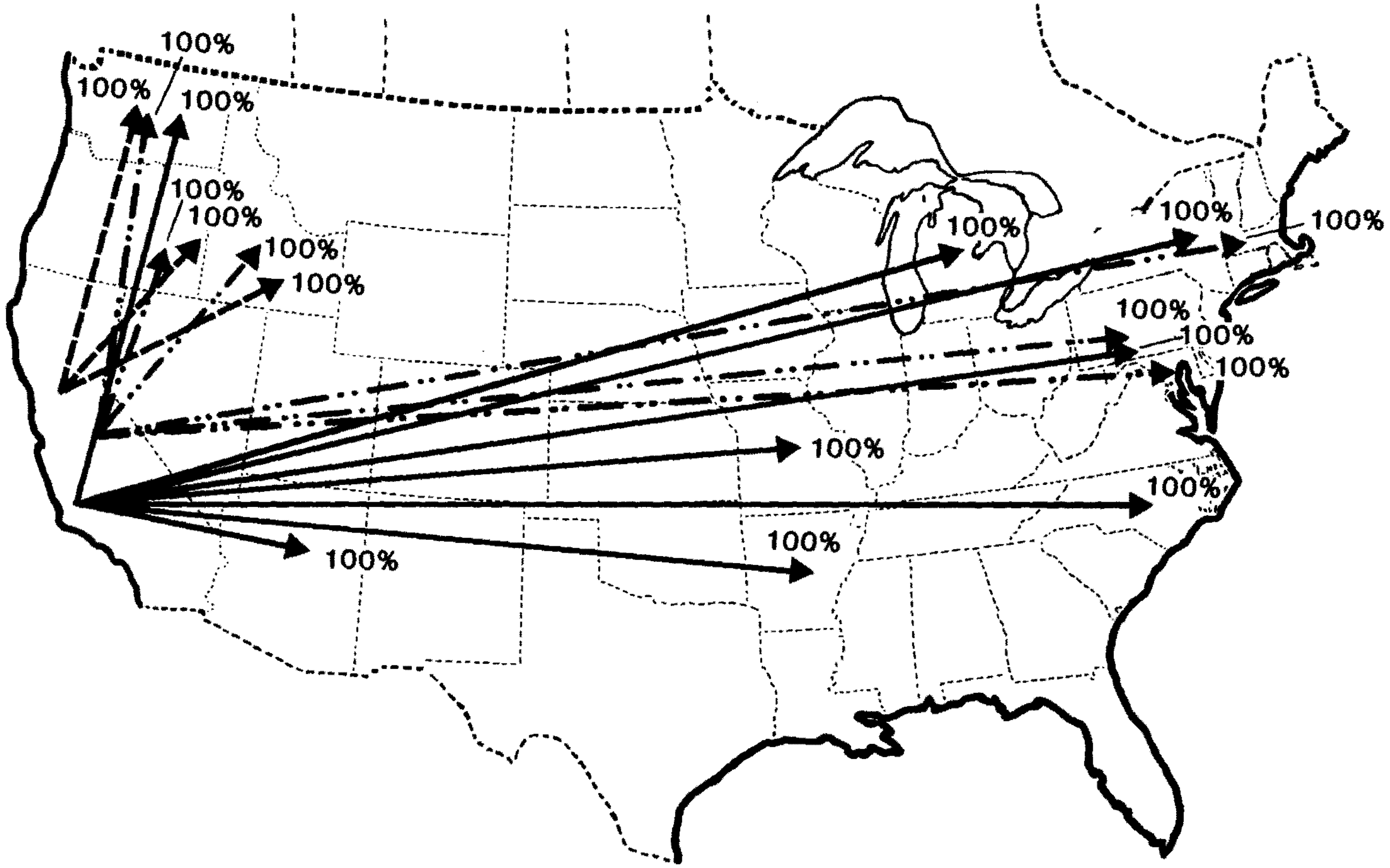


Figure 2a. Technological Transfer from Integrated Pest Management Research : California, Grapes (——), Apples (—··—), Pears, (— — —)



New York, Pears (• • •); Apples (—·—); Grapes (∼∼)

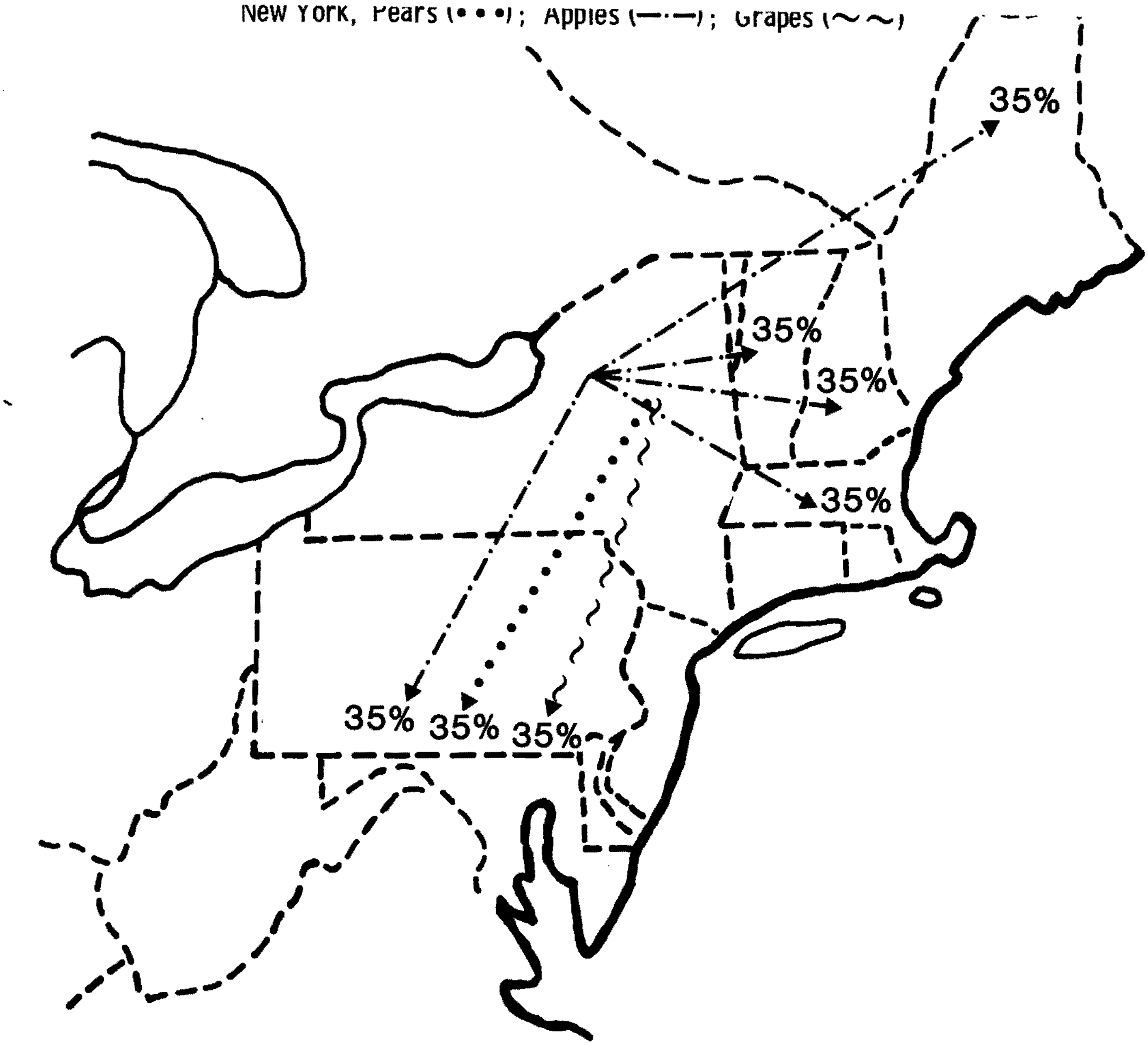


Figure 3a. Technological Transfer from Integrated Pest Management Research: Michigan, Peppermint (~ ~); Texas, Cattle (– – –); California, Cotton (—·—)

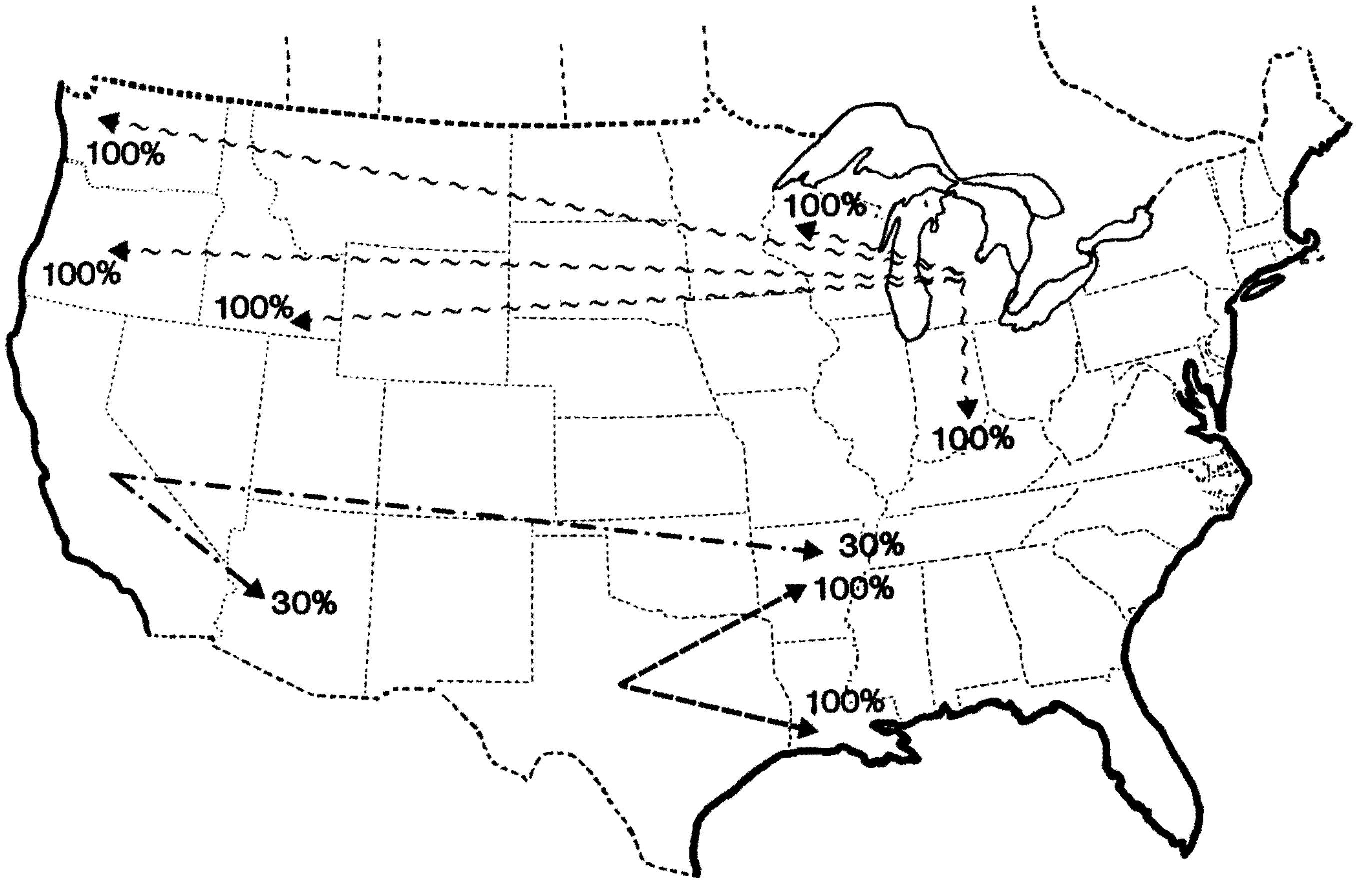


Figure 3b. Technological Transfer from Integrated Pest Management Research: Michigan, Forest (——); New York, Potatoes, Beans, Sweet Corn, Onions (—··—)

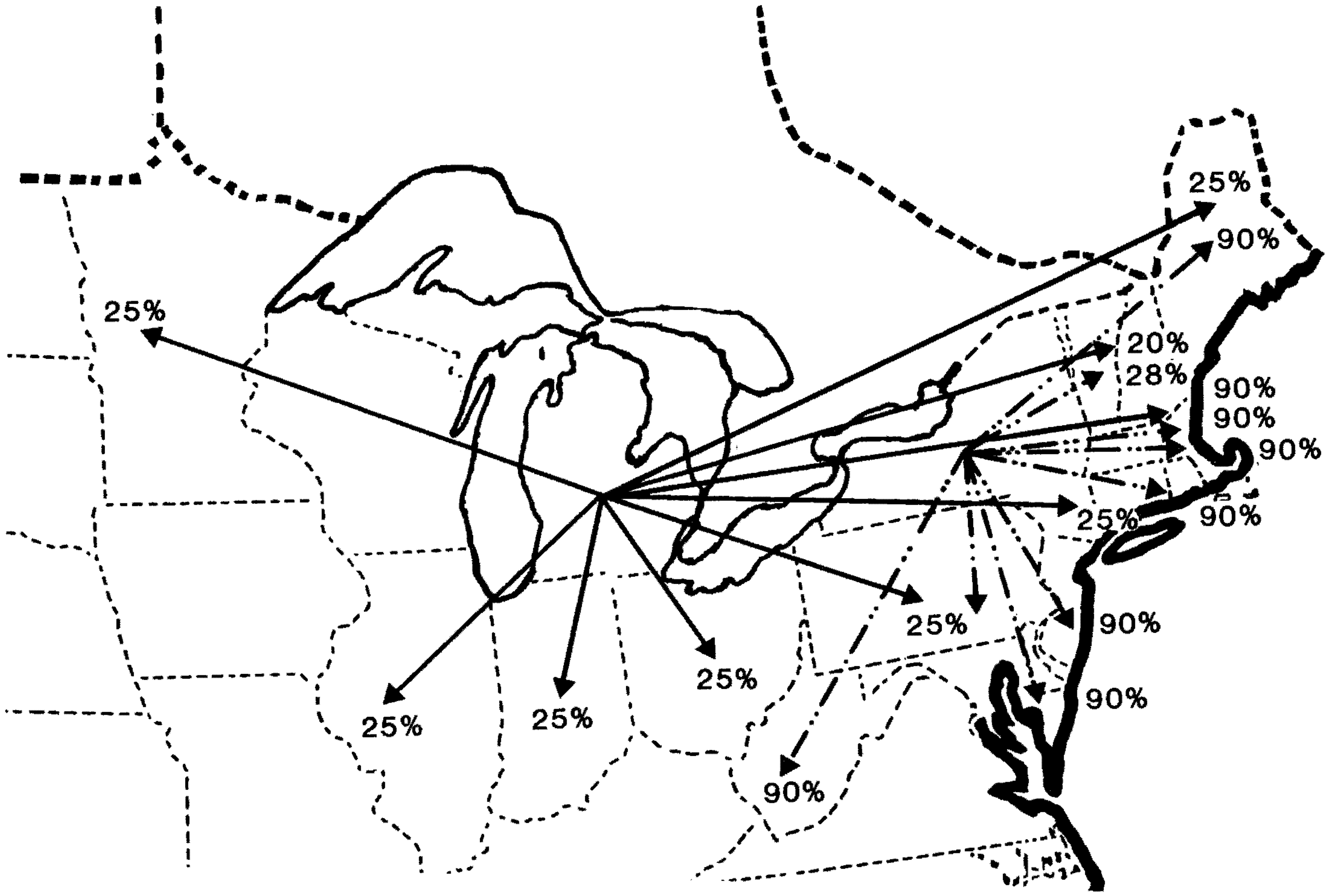


Figure 4. Technological Transfer from Integrated Pest Management Research: Michigan, Peaches, Apples, Plums, Pears

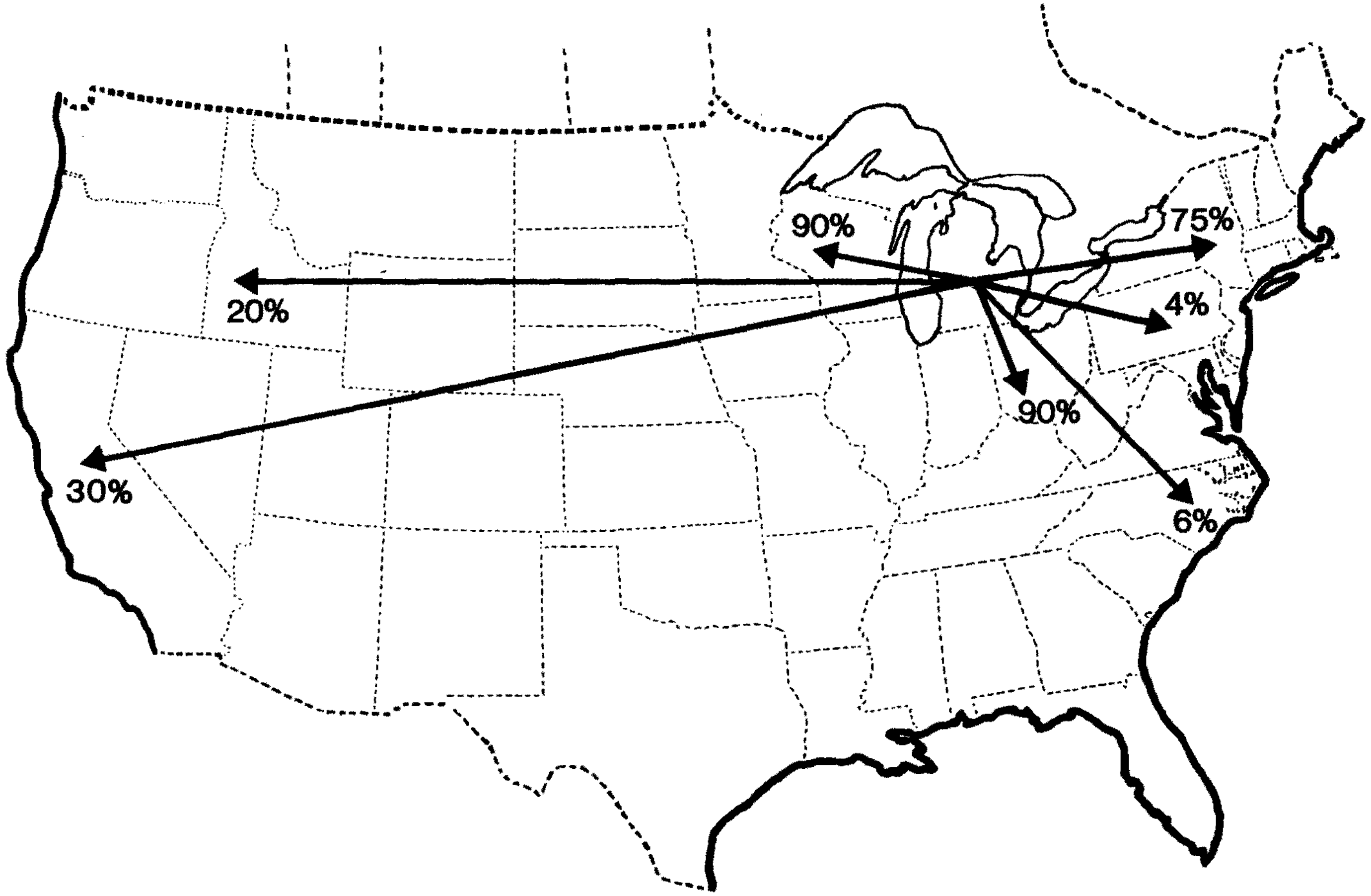


Figure 5. Technological Transfer from Integrated Pest Management Research : Indiana, Corn (——); Soybeans (—·—), Soft Red Winter Wheat (– – –)

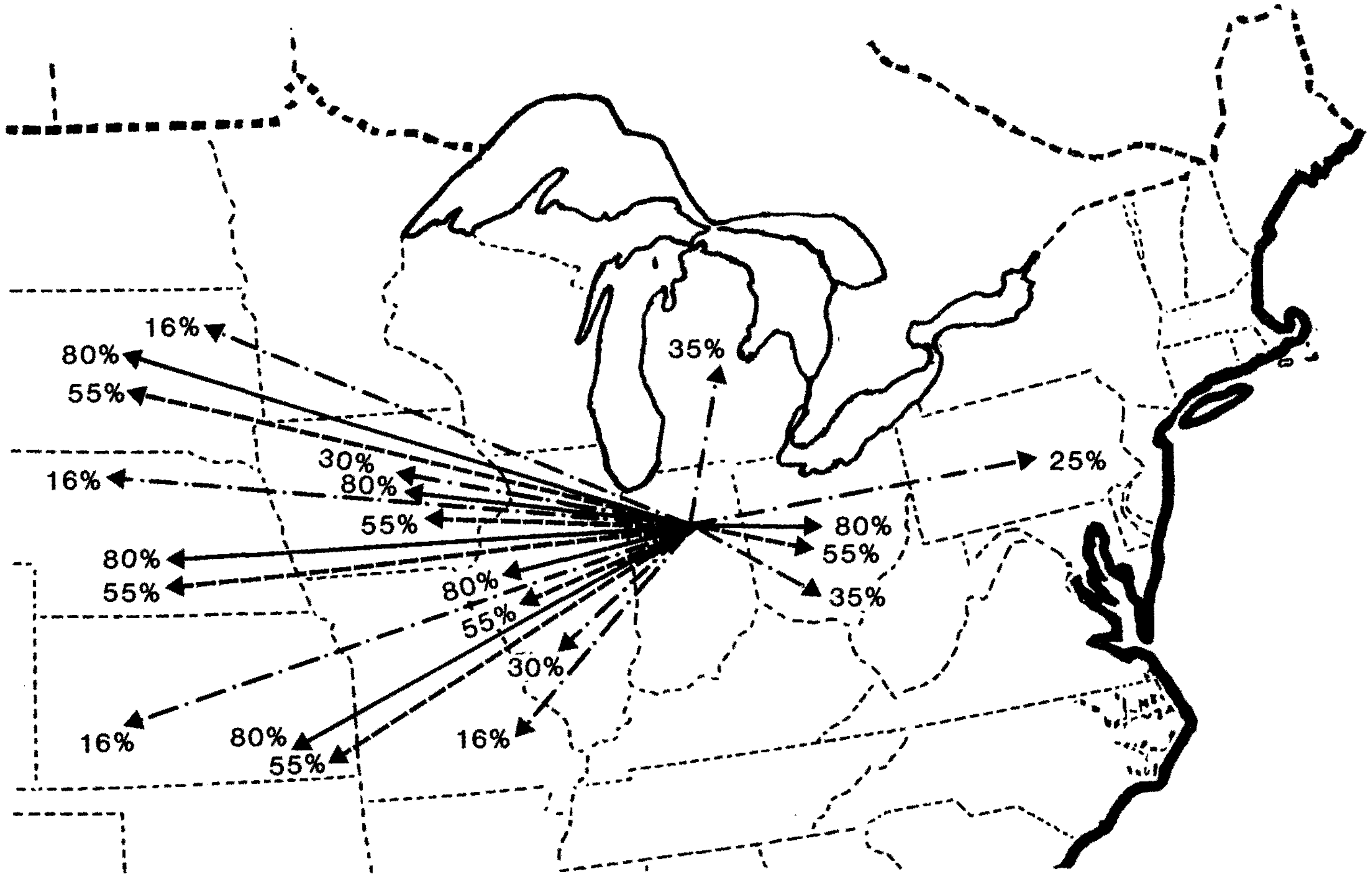
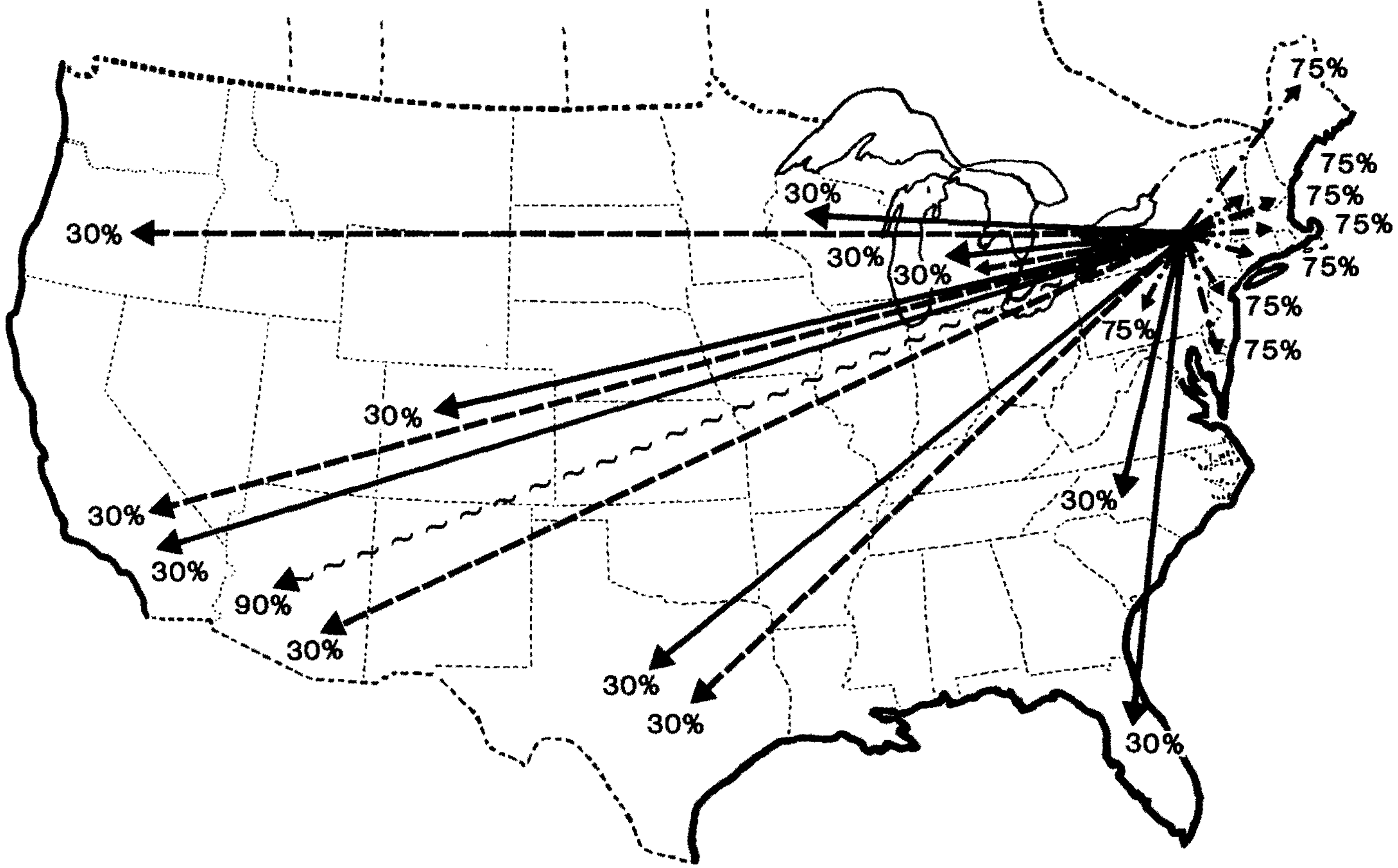


Figure 6. Technological Transfer from Integrated Pest Management Research: New York, Cabbage (——), Califlower (– – –), Lettuce (~ ~), Field Corn (—·—)



in California. The adoption profile was applied to the proportion of acreages in these states to estimate the total acreage of alfalfa that will adopt the program.

The extent of technology transfer within regions and between regions varies from crop to crop and is influenced by the nature of the IPM program being developed. An estimated 100% of the results of IPM programs for fruit trees such as grapes, apples, and pears developed in the California station is transferable to other states. Similar estimates were obtained for IPM research for cotton from California to other states, for cattle from Texas to other states, for peppermint from Michigan to other states, for alfalfa from Indiana to other states, and for grapes from New York to other states. The types of pest for which IPM is being developed influence the extent of technology transfer.

The estimated benefit-cost ratios, net present worth and internal rate of return in investments in IPM for the commodities considered in this study are shown in Table 1. Returns to investment were estimated for flow of benefits to years 1990, 1995, and 2000 with and without extension participation. Internal rate of return for the flow benefits to year 1990 with extension participation range from a high of 190% for soft red winter wheat to a low of less than zero for sweet corn. Extending the flow of benefits to year 1995 and year 2000 increased the internal rates of return slightly. The payoff to investments in pest management programs varies by commodities and is influenced by the pattern and magnitude of technology transfer within and between regions, the number of acres affected, the value of the output, the type of pest involved and the damage it causes, the adoption profile, and probability of research success. For the major agricultural commodities such as alfalfa, cotton, corn, cattle, potatoes, apples, fruits, and onions, the internal rates of return are in the 20% to 60% range.

Analysis of the results indicate that significant returns to investment in experiment station pest management research will not be realized without coordinated extension involvement in the dissemination and implementation of research results. Depending on the commodity and the estimated flow of benefits, approximately 7.2% to 100% of the expected benefit from pest management research will not be realized without extension participation (Table 2).

The importance of cooperative extension is influenced by the degree of risk associated with any change in the present practice of pesticide use. For pests that cause extensive damage on certain crops and for which changes in present

pest management programs will totally depend on the development of a well-designed extension program to convince producers of the values and the risks associated with the implementation of the new pest management program. The expected benefits from IPM for such crops as apples, grapes, citrus, pears, sweet corn, carrots, lettuce, peppers, cabbage, cantaloupe, asparagus, peppermint, sugarbeets, soybeans, and cotton will entirely depend on a well coordinated extension program (Table 2).

The Environmental Impact of Investment in Integrated Pest Management

Current and planned pest management programs are expected to reduce pesticide use significantly. The results of this study show an estimated 37.04 million lbs. of active toxic ingredients will be eliminated annually from use on 20 agricultural commodities (Table 3). The reduction in pesticide use is primarily due to the implementation of monitoring systems, proper timing of pesticide application, development of resistent varieties, and the introduction of biological control.

The reduction of an estimated 37.04 million lbs. of active toxic materials will lead to further future reduction in the use of pesticides by enhancing the effectiveness of biological control. Reduction in the use of pesticides will increase the population of the parasite species that are presently being destroyed by excessive toxic materials in the environment. The scientific judgment of the researchers and extension specialists interviewed for the purpose of this study suggest that the impact of IPM programs on the reduction of active toxic materials from the environment, development of resistent varieties, and the implementation of proper management systems will lead to a potential 50-70% reduction in the present pesticide use in the United States.

Summary

Extensive reliance on pesticides for the last three decades has resulted in frequent treatments with increasing dosages of chemicals. The broad ecological dictum of considering the whole interacting system in pest control was generally ignored. The practice increased production costs of many crops without alleviating the problem. The rising energy and pesticide costs combined with growing ecological and social concern about excessive pesticide use have focused scientists attention to the development of IPM programs that consider the biological, cultural, and ecological aspects of controlling pests. The United States International Biological Program (IBP) initiated in

	Alfalfa	Cotton	Corn	Grapes	Soybeans
1990[2]					
Without extension					
B/C ratio	0.8581	0.1173	1.3448	0.1335	---
N.P.W. ($ million)	-3.2	-59.7	1.9	18.5	---
I.R.R. (%)	8.07	<0	14.63	<0	---
1995[3]					
without extension					
B/C ratio	1.6991	0.1299	1.6041	0.2121	---
N.P.W. ($ million)	17.8	-67.9	3.4	-1.9	---
I.R.R. (%)	15.48	<0	16.40	<0	---
2000[4]					
without extension					
B/C ratio	2.1576	0.1361	1.7651	0.2521	---
N.P.W. ($ million)	30.9	-72.9	4.3	-19.5	---
I.R.R. (%)	17.21	<0	17.04	<0	---
1990[2]					
with extension					
B/C ratio	4.1927	2.2483	24.2404	4.9953	16.9464
N.P.W. ($ million)	75.0	84.5	131.1	85.5	19.6
I.R.R. (%)	36.66	61.00	59.02	76.63	125.11
1995[3]					
with extension					
B/C ratio	6.0981	2.4118	30.1247	5.6736	38.1756
N.P.W. ($ million)	130.1	110.1	164.3	113.6	45.8
I.R.R. (%)	38.25	61.21	59.26	76.80	128.83
2000[4]					
with extension					
B/C ratio	7.1375	2.4933	33.7784	6.0186	51.3573
N.P.W. ($ million)	164.3	126.1	185.0	131.1	62.02
I.R.R. (%)	38.51	61.23	59.28	76.81	128.88

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[1] The rates of return estimates are based on the low probability of research success shown in Appendix-Table 1.

[2] The flow of benefits is assumed to continue to 1990.

[3] The flow of benefits is assumed to continue to 1995.

[4] The flow of benefits is assumed to continue to 2000.

1971, has set the foundation for the development and implementation of IPM programs. The concept of IPM has received wide acceptance and is being implemented on several crops. The primary objective of this study is to evaluate the economic and environmental impact of investments in IPM in the United States.

An ex-ante approach was used to evaluate current and planned pest management programs in the United States. A set of questionnaires was developed to obtain the following information: (1) initiation and termination dates of research and extension projects for each commodity; (2) the probability of research success; (3) the probability and the adoption profile of research results with and without extension; (4) research, extension, and private resources required to develop, implement, and maintain the new technology; (5) the expected elimination of active toxic ingredients from the environment; (6) the expected changes in yield, quality, and cost of production ensuing from the implementation of the new technology; and (7) the pattern and extent of technological transfer. Personal interviews were conducted with researchers and extension specialists in the leading research and extension centers in IPM in the Northeast, the Northcentral, the South, and the Western Regions.

Analysis of the results shows that internal

	Cattle	Sorghum	Wheat	Potatoes	Sugarbeets
1990[2]					
without extension	0.5773	7.5647	15.7918	0.5228	---
B/C ratio	-3.4	2.9	10.2	-7.0	---
N.P.W. ($ million)	<0	73.75	133.76	1.05	---
I.R.R. (%)					
1995[3]					
without extension					
B/C ratio	0.7694	10.5322	20.4702	0.8307	---
N.P.W. ($ million)	-1.9	4.4	162.2	-3.3	---
I.R.R. (%)	5.94	74.42	134.19	7.80	---
2000[4]					
without extension					
B/C ratio	0.8765	12.3336	22.6437	1.0063	---
N.P.W. ($ million)	-1.1	5.2	199.5	.01	---
I.R.R. (%)	8.18	74.46	134.20	10.06	---
1990[2]					
with extension					
B/C ratio	1.5634	15.1302	27.3882	4.5804	89.5012
N.P.W. ($ million)	4.5	6.4	182.0	6.7	23.1
I.R.R. (%)	18.95	112.88	190.91	39.82	161.24
1995[3]					
with extension					
B/C ratio	2.0740	15.1302	35.0591	6.8347	123.9740
N.P.W. ($ million)	9.3	6.4	346.9	9.9	32.1
I.R.R. (%)	22.24	112.88	191.04	40.75	161.27
2000[4]					
B/C ratio	2.3589	21.0654	38.6229	8.1434	145.379
N.P.W. ($ million)	12.2	9.2	346.9	1.4	37.7
I.R.R. (%)	23.35	113.06	191.04	44.90	161.27

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[1] The rates of return estimates are based on the low probability of research success shown in Appendix-Table 1.

[2] The flow of benefits is assumed to continue to 1990.

[3] The flow of benefits is assumed to continue to 1995.

[4] The flow of benefits is assumed to continue to 2000.

rates of return to investment in pest management research and extension programs range from a high of 191% for soft red winter wheat to a negative return for sweet corn. The payoff to investment in pest management programs varies by commodity and is influenced by the magnitude of technology transfer within and between regions, number of acres involved, the value of the output, the type of pest and the damage it causes, the adoption profile, and the probability of research success. For the major agricultural commodities such as alfalfa, cotton, corn, cattle, potatoes, fruits, and onions, the internal rates of return are in the 20% to 60% range. The results also show that technology developed by a state experiment station is transferred and adopted by other states. The pattern and magnitude of technology transfer is affected by the nature of the technology and the type of crops and pests involved.

The results also show that significant returns to investment in experiment station pest management research will not be realized without extension involvement in the dissemination and implementation of the results. Depending on the commodity, approximately 7.2% to 100% of the expected benefits from research will not be realized without extension participation.

Significant environmental impacts are expected from the implementation of current and

1990[2] without extension					
B/C ratio	6.3456	0.2141	0.4309	---	4.3344
N.P.W. ($ million)	2.2	-1.4	-1.8	---	5.7
I.R.R. (%)	48.00	<0	<0	---	60.19
1995[3] without extension					
B/C ratio	8.3767	0.2431	0.6425	---	5.8086
N.P.W. ($ million)	3.2	-1.5	-1.1	---	9.5
I.R.R. (%)	49.19	<0	4.85	---	61.33
2000[4] without extension					
B/C ratio	9.5336	0.2580	0.7714	---	6.5299
N.P.W. ($ million)	3.8	-1.6	-.8	---	12.0
I.R.R. (%)	49.34	<0	7.30	---	61.43
1990[2] with extension					
B/C ratio	33.9104	1.0663	0.6617	5.4236	7.2704
N.P.W. ($ million)	13.6	.1	-1.4	15.7	10.7
I.R.R. (%)	108.36	11.88	3.91	101.76	86.56
1995[3] with extension					
B/C ratio	45.7806	1.4908	0.9731	6.0742	97.208
N.P.W. ($ million)	19.6	1.0	-.1	22.0	17.4
I.R.R. (%)	108.53	18.84	9.66	102.49	86.95
2000[4] with extension					
B/C ratio		1.7095	1.1599	6.5840	10.9197
N.P.W. ($ million)		1.5	.7	29.1	215.5
I.R.R. (%)		20.46	11.61	102.59	86.97

1/The rates of return estimates are based on the low probability of research success shown in Appendix-Table 1.

2/The flow of benefits is assumed to continue to 1990.

3/The flow of benefits is assumed to continue to 1995.

4/The flow of benefits is assumed to continue to 2000.

planned pest management programs. The results of this study show that an estimated 37.04 million lbs. of active toxic ingredients will be eliminated from use annually on 20 agricultural commodities. This reduction in toxic materials is expected through the implementation of monitoring systems, proper timing of pesticide application, development of resistant varieties, and the introduction of biological control.

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	Edible Tree Nuts	Stone Fruit	Sweet Corn	Onions	Peaches
1990[2]					
without extension					
B/C ratio	0.7877	0.3729	0.2350	1.5182	1.1505
N.P.W. ($ million)	-1.9	-1.7	-2.3	2.3	.06
I.R.R. (%)	5.86	<0	<0	16.27	13.33
1995[3]					
without extension					
B/C ratio	1.0048	0.5346	0.3206	1.9879	1.4169
N.P.W. ($ million)	.04	-1.3	-1.2	4.9	.1
I.R.R. (%)	10.07	3.16	<0	19.15	17.07
2000[4]					
without extension					
B/C ratio	1.1174	0.8574	0.3020	2.2435	1.5639
N.P.W. ($ million)	1.2	-.4	-1.3	6.5	.2
I.R.R. (%)	11.59	8.27	<0	20.00	18.23
1990[2]					
with extension					
B/C ratio	4.4983	2.6505	0.4283	4.1689	5.1774
N.P.W. ($ million)	31.5	4.6	-.9	14.4	1.5
I.R.R. (%)	52.49	30.47	<0	46.96	62.21
1995[3]					
with extension					
B/C ratio	4.3125	3.5777	0.5907	4.8237	6.3763
N.P.W. ($ million)	33.5	7.6	-.8	18.9	2.1
I.R.R. (%)	52.55	33.04	<0	47.36	62.86
2000[4]					
B/C ratio	4.2167	4.1153	0.6692	5.1788	7.0377
N.P.W. ($ million)	34.7	9.4	-.7	2.1	2.5
I.R.R. (%)	52.55	33.54	1.72	47.42	62.91

1/The rates of return estimates are based on the low probability of research success shown in Appendix-Table 1.

2/The flow of benefits is assumed to continue to 1990.

3/The flow of benefits is assumed to continue to 1995.

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	Pears	Carrots	Lettuce	Peppers	Pecans
1990[2] without extension					
B/C ratio	---	---	---	---	2.4275
N.P.W. ($ million)	---	---	---	---	1.0
I.R.R. (%)	---	---	---	---	35.24
1995[3] without extension					
B/C ratio	---	---	---	---	3.0495
N.P.W. ($ million)	---	---	---	---	1.6
I.R.R. (%)	---	---	---	---	38.00
2000[4] without extension					
B/C ratio	---	---	---	---	3.3584
N.P.W. ($ million)	---	---	---	---	2.0
I.R.R. (%)	---	---	---	---	38.45
1990[2] with extension					
B/C ratio	2.0146	1.4188	47.9763	9.2298	6.4804
N.P.W. ($ million)	.4	.01	1.2	2.1	3.8
I.R.R. (%)	33.37	15.56	96.65	55.87	76.42
1995[3] with extension					
B/C ratio	15.6945	1.6981	57.4237	12.7847	8.0535
N.P.W. ($ million)	5.4	.02	1.5	3.0	5.6
I.R.R. (%)	79.04	17.47	96.69	56.75	77.23
2000[4] with extension					
B/C ratio	23.6742	1.8624	62.9817	14.9921	8.8349
N.P.W. ($ million)	8.6	.02	1.6	3.6	6.8
I.R.R. (%)	80.21	18.13	96.69	56.84	77.27

1/The rates of return estimates are based on the low probability of research success shown in Appendix-Table 1.
2/The flow of benefits is assumed to continue to 1990.
3/The flow of benefits is assumed to continue to 1995.
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	Cabbage	Cauliflower	Asparagus	Cantaloupe	Pepper-mint
1990[2]					
without extension					
B/C ratio	---	1.6988	---	---	---
N.P.W. ($ million)	---	.3	---	---	---
I.R.R. (%)	---	22.09	---	---	---
1995[3]					
without extension					
B/C ratio	---	5.2759	---	---	---
N.P.W. ($ million)	---	2.0	---	---	---
I.R.R. (%)	---	36.69	---	---	---
2000[4]					
without extension					
B/C ratio	---	8.1941	---	---	---
N.P.W. ($ million)	---	3.5	---	---	---
I.R.R. (%)	---	38.92	---	---	---
1990[2]					
with extension					
B/C ratio	3.6385	1.6988	11.9149	22.0702	3.6088
N.P.W. ($ million)	3.8	.3	14.3	5.5	10.3
I.R.R. (%)	34.98	22.09	138.19	85.23	101.11
1995[3]					
with extension					
B/C ratio	4.3623	6.5732	12.6429	30.5708	3.6832
N.P.W. ($ million)	5.1	2.7	16.2	7.7	12.1
I.R.R. (%)	35.85	40.33	138.19	85.54	101.11
2000[4]					
with extension					
B/C ratio	4.7810	9.4714	13.0385	35.8491	3.7212
N.P.W. ($ million)	5.9	4.1	18.1	9.1	13.1
I.R.R. (%)	36.02	41.93	138.19	85.56	101.11

1/The rates of return estimates are based on the low probability of research success shown in Appendix-Table 1.

2/The flow of benefits is assumed to continue to 1990.

3/The flow of benefits is assumed to continue to 1995.

4/The flow of benefits is assumed to continue to 2000.

ticipation, by commodity.

Commodity	1990 (%)	1995 (%)	2000 (%)
Tomatoes	55.7	54.7	54.5
Potatoes	97.4	80.9	77.6
Apples	100	100	100
Grapes	100	100	100
Beans	100	49.8	37.1
Cattle	100	73.3	65.00
Citrus	100	100	100
Forest	30.5	29.5	29.4
Edible Tree Nuts	88.8	80.8	77.9
Stone Fruit	100	90.4	75.3
Sweet Corn	100	100	100
Corn	75.2	71.9	71.3
Onions	65.4	59.6	57.8
Pears	100	100	100
Carrots	100	100	100
Lettuce	100	100	100
Peppers	100	100	100
Sorghum	34.7	34.1	34.1
Pecans	53.39	50.8	50.2
Cabbage	100	100	100
Cauliflower	0	9	7.2
Cantaloupe	100	100	100
Sugarbeets	100	100	100
Asparagus	100	100	100
Peaches	78.6	72.8	71.00
Peppermint	100	100	100
Soybeans	100	100	100
Alfalfa	78.00	58.9	55.3
Cotton	100	100	100
Wheat	29.9	29.7	29.7

planned pest management research and extension programs by commodity.

Commodity	Reduction in Active Toxic Ingredient (mil.lb.)
Alfalfa	1.45
Cotton	15.90
Corn	2.80
Grapes	1.15
Soybeans	5.10
Sorghum	6.00
Potatoes	1.20
Tomatoes	.01
Apples	1.15
Beans	.05
Citrus	.12
Edible Tree Nuts	.40
Stone Fruit	1.17
Sweet Corn	.10
Onions	.08
Pears	.03
Pecans	.03
Cabbage	.15
Cauliflower	.05
Peaches	.10
Total	37.04

SUBJECTIVITY IN EX ANTE RESEARCH EVALUATION

C. Richard Shumway*

Abstract

This essay is a critique of research evaluation research. Considerable evidence exists that agricultural research conducted during the era when projects were chosen by diffuse selection systems yielded extraordinarily high returns. It is not obvious that the formalized, quantitative, and typically centralized selection models can be expected to produce higher contemporary returns than the decentralized informal mechanisms. All ex ante evaluations are intrinsically subjective, regardless of technique used to generate the evaluation. The extreme uncertainty surrounding the nonrepetitive new-knowledge production function further limits the potential of the sophisticated selection procedures. Perhaps of greatest importance, however, are the high costs imposed by these procedures in terms of scientists' time, morale, and "artistic" research tool atrophication.

Purpose of Research Evaluation

Much effort in recent years has been invested in devising new methodologies for evaluating public agricultural research. Reasons for wanting to evaluate research are many and varied. They range from measurement of the historical rate of return for research investments to assessment of the influence of various organizational participants on research selection and conduct. However, just as the many and diverse intermediate objectives of economic research ultimately funnel into the overriding end goal of improving predictive performance, so the major objective of research evaluation research condenses to improving predictions of costs and benefits of future research. The ultimate practical objective of all this work is purely ex ante, i.e., to provide relevant information for future funding decisions. Determining the productivity of past investments is mainly academic as they are sunk costs. Their relevance must be measured by the extent to which they are useful for making variable cost (i.e., present and future) decisions.

Do We Need Formal Ex Ante Analysis?

Ex ante evaluation of research alternatives is not a new concept. It has always been conducted in some fashion at one or more levels in the research organizational hierarchy. Historically, the major assessment of project alternatives has been made by the individual scientist acting as an entrepreneur on behalf of his own professional life. Administrators have reviewed proposals submitted by scientists and approved, disapproved, or modified them, but the major administrative roles have been more in trying to increase total funding and in selecting scientists who would be with the organization for extended periods than in selecting individual projects. Of course, the role of administation varies from organization to organization, but few have implemented formal, systematic evaluation procedures for quantitatively measuring the worth of one research area against another.

The justification for proposing a change in the way ex ante research evaluation is conducted must ultimately rest on one of the following perceptions: (1) the current system is not working well, or (2) some evidence exists that even though the current system is working well, it could do significantly better with a change.1/ Let's investigate brifely whether there are sufficient grounds for either perception in agricultural research.

Importantly, the historical rate of return on agricultural research investments provides valuable information relevant to the first possible justification for change. Although some assumptions underlying the various models can be challenged and some of the data used are disquietingly shallow, the high rate-of-return estimates are profoundly robust. Nearly all studies have estimated a historical rate of

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ural investments (Evenson, Waggoner, and Ruttan, p. 1103). This is true not only with regard to studies of aggregate U.S. agricultural research investments, but also U.S. regional investments, foreign investments, and commodity-specific investments. Consequently, unless equity costs of such research have been extremely high, the only plausible conclusion from the rate-of-return studies is that there has been general underinvestment in agricultural research. Some evidence exists that the rate of return on aggregate U.S. agricultural research investments may be decreasing with time (Peterson and Fitzharris, p. 78; Evenson, et al., p. 1103), but the most recent estimates are still in excess of 20% per year. Thus, underinvestment in agricultural research is still apparent.

With such high estimates of historical rates of return, it is difficult to argue logically that the seemingly loose *ex ante* evaluation procedures used in the past haven't worked well. So the first justification for arguing a need for change must be dismissed.

Arriving at a clear conclusion concerning the second justification is not so easy. It is a truism that we can always do better. Unfortunately that truism has little practical value. We are not working with optimum vs. suboptimum because in *ex ante* evaluation the optimum is indeterminate. There is simply too much uncertainty in the nonrepetitive new-knowledge production function. The primary issue in our evaluation of *ex ante* evaluation procedures is not whether some bad projects have been funded in the past or whether more will be in the future. It is fundamentally whether we will decrease the errors and increase the total payoff from research efforts by changing the evaluation procedure.

Arguments in favor of change often focus on the benefits of "systematic" evaluations and greater "objectivity." Many of the proposed alternative evaluation procedures are clearly systematic. They permit categorizing, ordering, comparing, and summarizing data in ways that are internally consistent and thus systematic. The question is whether they permit any greater objectivity than the evaluation methods used historically. This issue will be probed more deeply.

Role of Objective Data in *Ex Ante* Analysis

Objectivity is obviously preferred to subjectivity because decisions made objectively can be more easily defended via rational thought processes. It is easier to convince another person of the factual nature of objective than of subjective observations. Since the future is unknown and highly uncertain, the only objective data are historical observations. Because methods for such historical data is a logical place to begin. If it is possible to confidently correlate historical research performance with future research payoff at a very micro level, our evaluation procedures could introduce a measure of objectivism that would increase their administrative value considerably.

Within the profession, there is considerable expectation that a scientist who has proved to be highly productive in the past is a good risk for future investments of support funds. Although examples to the contrary abound, there is strong sentiment that historical performance of a scientist is a useful tool for predicting future productivity. Thus, funding agencies continue to invest a large share of their money with proven researchers. There appears to be little risk that investments in a Samuelson or a Friedman will not pay rich dividends.

Unfortunately, no research organization is made up of all Samuelsons and Friedmans. Few have even one. How then can these administrators take advantage of historical information to help them determine which additional research areas to promote and which to retrench from?

I have previously proposed a set of four sufficient conditions that would permit the use of historical information at the research area level in objectively predicting future payoff (Shumway, 1977, p. 192). The conditions are:
(1) proposed projects are competitive for available resources
(2) research technology used on each historical and proposed project is of comparable quality for its time
(3) the production function for new knowledge discovery is characterized by an S-shaped production function, and
(4) each project represents a small movement along the knowledge production function.

These four conditions are sufficient to establish an orderly relationship between past and future research payoff. I have made a defense for each condition, but the defense for conditions (3) and (4) remains the weakest. The likelihood that the new knowledge production function is anything close to a smooth S-shape seems quite low. A less restrictive concave production function would still be sufficient, but it would have to be reasonably smooth. It is the smoothness property that is most in question.

Because these conditions have not been tested as formal hypotheses, arguments that there is a more orderly than random relationship between past and future research payoff remain conjectural. Since originally proposing these conditions, my own confidence in their general satisfaction has diminished considerably. Based on four conditions being met in all, or even most, of the applied research areas of any state or federal agricultural research unit is quite low.

It is true, for example, that breakthroughs in hybrid corn research have had important effects on hybrid grain sorghum and wheat research. But what has been the payoff from recent genetic research on corn? The marginal physical product of genetic research on corn could be characterized more as a few important blips (e.g., male sterile techniques, upright leaves, and high-lysine varieties) and one huge blimp (hybrids) than as anything close to a smooth function.

While hard scientific data on the subject are lacking, a few case studies document the need to be cautious not to overestimate the value of objective data for the *ex ante* funding decision. It appears unlikely that my sufficient conditions will prove very useful. Unless someone identifies another set with a considerably higher likelihood of being met, objective data will continue to play a minor role in *ex ante* research evaluation.

Many casual observers, including some research administrators and even some analysts, mistakenly attribute objectivism to certain evaluation techniques. The fallacy is in equating objectivity with quantifiability. Many techniques do use quantitative and/or qualitative inputs and provide quantitative evaluation outputs, but all *ex ante* research evaluation procedures are inherently subjective. The only difference is where subjectivity enters and how it is processed.

With Q-sort, subjectivity is imposed by the administrator at the highest level of abstraction in grouping projects into categories of similar perceived overall worth. With scoring models, subjectivity determines the specification and weighting of criteria and the categorization of each project relative to each criterion. Only the computation of the overall score proceeds in an "objective" fashion (Moore and Baker). With *ex ante* benefit-cost and rate-of-return estimates, subjectivity is also inherent in the estimates of both research benefits and investment costs (e.g., Araji et al). The predicted benefit-cost ratio and the rate-of-return estimate are quantified, but they are nonetheless subjectively based. Formalized optimization models (e.g., Shumway and Hwang) rely on subjective evaluations of the relative importance of objectives, expected achievement of objectives, probability of success, and expected cost. Even Rausser et al's recently proposed four-stage evaluation procedure is based almost exclusively on subjective data.

The only contributions any of the formal *ex* tivity, (2) suggest collection of objective information relevant to formation of subjective assessments, (3) insert subjectivity in forms where it is easiest for administrators and scientists or where the greatest confidence in its validity exists, and (4) process subjective data systematically to feed back information relevant to the funding decision. They cannot make objective outputs out of subjective inputs no matter how precise and elegant they may appear. Consequently, the legitimate role of subjectivity in *ex ante* evaluation needs to be clearly recognized and respected.

Assessment of Formal *Ex Ante* Evaluation Procedures

It is evident that many of the formal evaluation procedures are systematic. It is not clear they are in any sense more conducive of objectivity than the commonly used methods of evaluation. The fact that systematic evaluation procedures have been recommended to research administrators for at least 15 years and few have implemented them is strong *prima facie* evidence that their costs outweigh their perceived benefits.

By way of quaint but hopefully relevant comparison, if a car is broken, the mechanic tries to fix it. However, if it is running well and is getting better gas mileage and emits fewer pollutants than other comparable cars, he leaves it alone. He doesn't overhaul it until he has some evidence it can perform better than it is now.

The agricultural research establishment is not perfect, but it has performed well in the past without formal *ex ante* evaluation techniques. Further, there is no convincing evidence it will perform any better in the future with them. A heavy burden of proof that administrators need sophisticated and formalized *ex ante* research evaluation systems still rests upon the system developers.

Administration-Scientist Synergism

It is entirely possible that efforts in developing relevant evaluation techniques have focused on the wrong person. Administrators must make project selection decisions. But the alternatives they select from are formulated mainly by scientists, not by administrators. The organization must have proposals generated by imaginative, capable scientists who are well tuned to the problems of the public and the respective disciplines, or the administrators have only hollow project selection decisions to make.

A serious potential risk emanates from all the attention given to systematic and rigorous *ex* ject selection will lead to submission of a larger number of proposals but with lower quality research being conducted on all of them. The larger number of proposals permits administrators to exercise their responsibility of decision-making. But, will the quality and quantity of research conducted by the organization be as great as when performed by well-motivated scientific entrepreneurs unencumbered by either the paper requirements or the annoyance of organizational demands for *ex ante* evaluation and *ex post* accountability? It may be that the best service the analysts can perform is to help administrators articulate relevant criteria to guide administration-scientist interaction so scientists can be more productive.

Unless the research organization is going to change scientists more often than any do now, the only relevant research alternatives are those that can be pursued by existing scientists plus a few new ones. Therefore, the appropriate place to begin the evaluation process is with the scientist. How can this entrepreneur be helped to select projects with high potential payoff?

Problem selection is generally the most important and most difficult part of inquiry. It is important because it delimits the range of investigation and establishes upper limits, although undefined, on the potential payoff of the inquiry. It is difficult largely because there are no formal rules that can be given by which scientists can learn to ask significant questions that lead to a perception and statement of significant problems. The ability to formulate important problems whose solution may also help solve other problems is often considered a rare gift.

Yet, some relevant guides can be identified to assist this learning process and sharpen the subjective perception of relevance. Sources of valuable signals must be cultivated, rational thought processes must be used in serious evaluation, and the subconscious must not be totally throttled.

Sources of Signals Concerning Research Priorities

Only a weak economic market exists for public research products since few products are sold and most are placed in the public domain at little or no charge to the user. However, an obvious source of research priority signals is still the market system. There is a strong economic market on the resource side of research, i.e., the job market. Bids and offers for particular scientists largely reflect a perception of the relevance, quality, and quantity of their work. While such offers are determined primarily by intermediate research products (i.e., publica-

Market signals also come from the user level in the form of legislative support or lack of support for research budgets. If the political processes work smoothly, legislators are going to reflect the attitudes of a majority of their constituents. Thus, the budget message is a type of economic signal from the end-product market. These signals in some form flow through the research administration. Administrative priorities consequently become proxies for public preferences.

While these economic signals are important, they are not sufficient for *ex ante* evaluation because they are either not sufficiently specific or they are based on assessments of work already completed. Additional sources of signals need to be cultivated.

The individual researcher needs communication linkages to determine current societal priorities. Hildreth and Castle (pp. 23-25) divide societal expressions of priorities into two forms: felt needs and gaps between goals and achievements. Both types of problems necessitate maintaining a finger on the societal pulse at the grassroots level. Because our clientele include all of society, it is difficult to maintain an accurate sense of needs and problems. However, we do have the infrastructure in place to pick up such signals from a large subset of our clientele if we will just use it. The Extension Service is charged with the responsibility of taking new knowledge discovered by agricultural researchers, packaging it in lay terminology, and delivering it to the relevant publics. Because they are in continual contact with the ultimate users of our research products, they are in an excellent position to also observe and listen to what those users think they want in terms of additional knowledge. Often that knowledge requires research, so their desires must be transmitted so that a research project can be conceptualized to provide answers to the issues raised. Strong two-way bridges of communication between research and extension must be developed to permit flow of research priority signals to researchers as well as new knowledge to users. Too often these communication bridges are weakened by real or fancied arrogance, indifference, or disdain.

The individual researcher also needs to develop communication linkages for anticipating future societal problems and preparing to help resolve them. It is the responsibility of the profession to address problems not yet faced and to build the theoretical structure and analytical tools to deal with them when they occur. Hildreth and Castle (pp. 25-26) also divide professional expressions of problems into two forms:

lectual difficulty. How many scientific breakthroughs have come because a scientist grappled with a perceived problem that didn't mesh with his theoretical scheme? How many profound discoveries have occurred because a scientist sought to untangle an intellectual paradox without any real perception of the possible practical ramifications of such an inquiry? Sources of signals to hone the scientist's perception of such theoretical research priorities include his own reading, attending professional meetings, and interacting with other scientists.

Of course, none of these sources of signals is sufficient alone. The scientist who has confined his entire attention to interaction with other scientists may find some applications of his theoretical work that could have highly fruitful consequences in resolving practical problems. Likewise, the researcher who is tuned only to current societal problems may greatly lengthen the long-term relevance of his work by studying associated theoretical and analytical developments.

Project Selection by the Scientist

By greasing the communication skids for problem identification, the scientist will always find himself faced with far more interesting and important research problems than he can possibly address. The next challenge is to establish his own set of priorities so he can propose those projects to the administration that he considers to have the highest payoff. It is unlikely that the quantitative evaluation models will be very useful to him, but a few simple questions may help him consider relevant issues. A set of potentially helpful questions for focusing one's thought processes includes the following:
(1) Who is your clientele?
(2) What are your priorities as to audience service (e.g., policymakers, researchers, farmers)?
(3) To whom is the problem important?
(4) To how many is the problem important?
(5) How much benefit will the clientele receive if this problem is solved?
(6) Do you have the analytical tools to conduct the research?
(7) What is the likelihood that your research effort will provide (or at least contribute to) a solution to the problem?
(8) What are the expected research costs (money and time)?
(9) What are the expected implementation costs?

No weights are suggested. Answers to these or similar questions help to identify weak links in the proposed study and promote communication between scientist and administrator. It is possible that his answers to questions 1 and 2 may be different than his administrator would like them to be, but explicitly defining them can be valuable in uncovering differences that fusing interaction between the two.

"Artistic Considerations"

Because identification and pursuit of significant research problems is not an exact science, the role of nonobjective research tools also needs to be addressed. In a recent article, Ladd identified some of the most frequently used, versatile, and valuable research tools, none of which lend themselves to formal incorporation in a quantitative *ex ante* project evaluation model. They include the subconscious mental processes of imagination, intuition, and hunch, the unpredictable role of chance and serendipity, and the stimulating effects both on the subconscious and on research efficiency from writing. These artistic tools are probably at least as important to productive research as are the orderly and systematic rational thought processes. Consequently, whatever procedures are considered to assure *ex ante* evaluation and *ex post* accountability ought to be weighed carefully against any possible negative impact on these valuable research tools.

Conflicting Signals

One of the most difficult challenges facing administrators is the resolution of conflicts. Signals coming from different sources are not going to harmonize. The noise must be filtered in order to make order out of seeming confusion. Even with filtering, however, it would be a rare phenomenon to discover that all signals are directed to a single goal. What benefits one group typically hurts another.

Order suggests that a unifying goal should be pursued and all intermediate objectives should be clearly directed to the ultimate goal. However, research is an inherently uncertain production process. The search for new knowledge is laden with heavy risks and many dead ends. Consequently, it may be unwise for a research organization to establish a single overriding objective. Perhaps it should deliberately be a little schizophrenic and simultaneously pursue conflicting goals in order to be prepared for alternative conditions. For example, agricultural policy research in recent years has shifted from fundamental concern about managing surpluses to world hunger back to managing surpluses again. It is quite likely that world hunger will re-emerge as a major issue as soon as the political scene changes.

An experiment station cannot afford to concern itself exclusively with increasing production efficiency to the exclusion of marketing efficiency and equity. Any particular researcher may be single minded, but the organization must generally be concerned with a multiplicity

Conclusions

Four concluding recommendations are drawn from this attempt to elaborate the relevance of subjectivity in ex ante research evaluation:

(1) Let's be realistic about the contribution formal research evaluation techniques can make. No more should be promised than can be delivered. Quantification is not synonymous with "better." Negative impacts on scientist morale, ambition, and imagination must be weighed carefully against any expected benefits from increasing the planning, evaluation, and accountability functions of the organization.

(2) The prominent place of subjectivity in ex ante evaluation needs formal recognition and respect. Just as quantification does not mean better, neither does it imply objectivity. Any ex ante evaluation is intrinsically subjective. Objective historical observations may be relevant but the linkage between past and future knowledge generation is sufficiently weak to require gross subjective synthesis and assessment.

(3) Instead of worrying so much about dividing an existing pie among many competitive alternatives, let's concentrate on educating administrators how to relevantly use historical data. Historical rate-of-return estimates are sufficiently high and robust to imply that the major deficiency has not been in allocation but in level of overall investment. In seems clear there has been public underinvestment in agricultural research.

(4) The role of the individual scientist in ex ante evaluation warrants considerably more attention. Without his generation of ideas and aggressive pursuit of interesting problems, the research organization would stagnate regardless of the valiant efforts of the administration. He is the first and most important participant in the research evaluation process. He is fundamentally concerned with and involved in project selection. Evaluation techniques that fail to recognize that crucial linkage or demand additional energies from him in documentation and accountability for the system's sake are probably doomed to a dismal failure.

Footnotes

1/One of the reviewers suggested a third reason for proposing a change in ex ante research evaluation--budget appropriators insist on a change in the evaluation process before they will appropriate. Actually, this is merely a symptom that the appropriators have one of the two perceptions identified in the text.

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EX ANTE ASSESSMENT OF CONSUMPTION AND NUTRITION EFFECTS OF AGRICULTURAL RESEARCH

Per Pinstrup-Andersen*

Current and expected future malnutrition has been used extensively in support of investment in research on food production. However, expected nutritional effects do not usually play a significant role in establishing priorities within such research and designing the desired technology. Expected impact on total food or nutrient supply has been used as a proxy for relative nutritional impact of alternative lines of research. However, the relative change in supply is a poor indicator of relative nutritional impact.

There are three principle reasons for this. First, the proportion of the total supply change which affects nutrient-deficient groups varies among research projects. Secondly, the adjustment in the consumption of foods, other than those for which supply is changed, may be of considerable importance in determining the final nutritional implications and, thirdly, the nutritional status is affected by the magnitudes and distribution of incomes generated by the particular research output. While the magnitude of incomes generated is likely to be related to the magnitude of the supply change, its distribution need not be.

The nutritional effect of a given line of research depends on the resulting change in nutrient consumption by deficient groups. But the resulting change in nutrient consumption by deficient groups is determined by a number of factors, of which change in total food supply is but one. Thus, efforts to incorporate nutritional goals into agricultural research planning must look beyond expected supply effects.

Decisionmakers in agricultural research who wish to incorporate nutritional goals into research planning are severely constrained by the lack of supporting research on this topic. The purposes of this paper are to explore how nutritional goals or an acceptable proxy for such goals may be considered and to suggest supporting research of high priority. The first part of the paper outlines the issues and relationships to be considered. An approach for dealing with nutritional effects of agricultural research and technological change is suggested next and the paper finalized with an outline of urgent research needs.

Issues and Relationships

Nutritional considerations may be incorporated into agricultural research planning either by orienting the research itself toward the achievement of nutritional goals or by identifying associated measures to facilitate the achievement of these goals or correct or compensate for undesired nutritional effects of research. Such measures may consist of projects or policy measures of various kinds. Whether nutritional considerations are best dealt with through research and technology design or through complementary measures depends on the particular set of circumstances. In either case, however, it is essential to pay explicit attention to nutritional effects of research if the achievement of nutritional goals is of high priority. Modifications in technology design or introduction of complementary measures may have significant nutritional effects without causing unacceptable changes in the achievement of other goals. Which tradeoffs related to the achievement of conflicting goals are acceptable is, of course, a political question. But to deal effectively with this question, the tradeoffs must be explicitly considered. Merely assuming that increasing food production will result in improved nutrition or that increasing production of non-food cash crops will have no adverse nutritional effects is to avoid the issue. Positive nutritional effects may be greatly enhanced and negative effects avoided if nutritional issues are considered along with other issues in research planning.

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research project and the nutritional status as well as the key parameters for which data should be sought and analysis performed. Probability of success in research, and the associated research costs and time requirements are not shown. A given research output provides the point of departure.

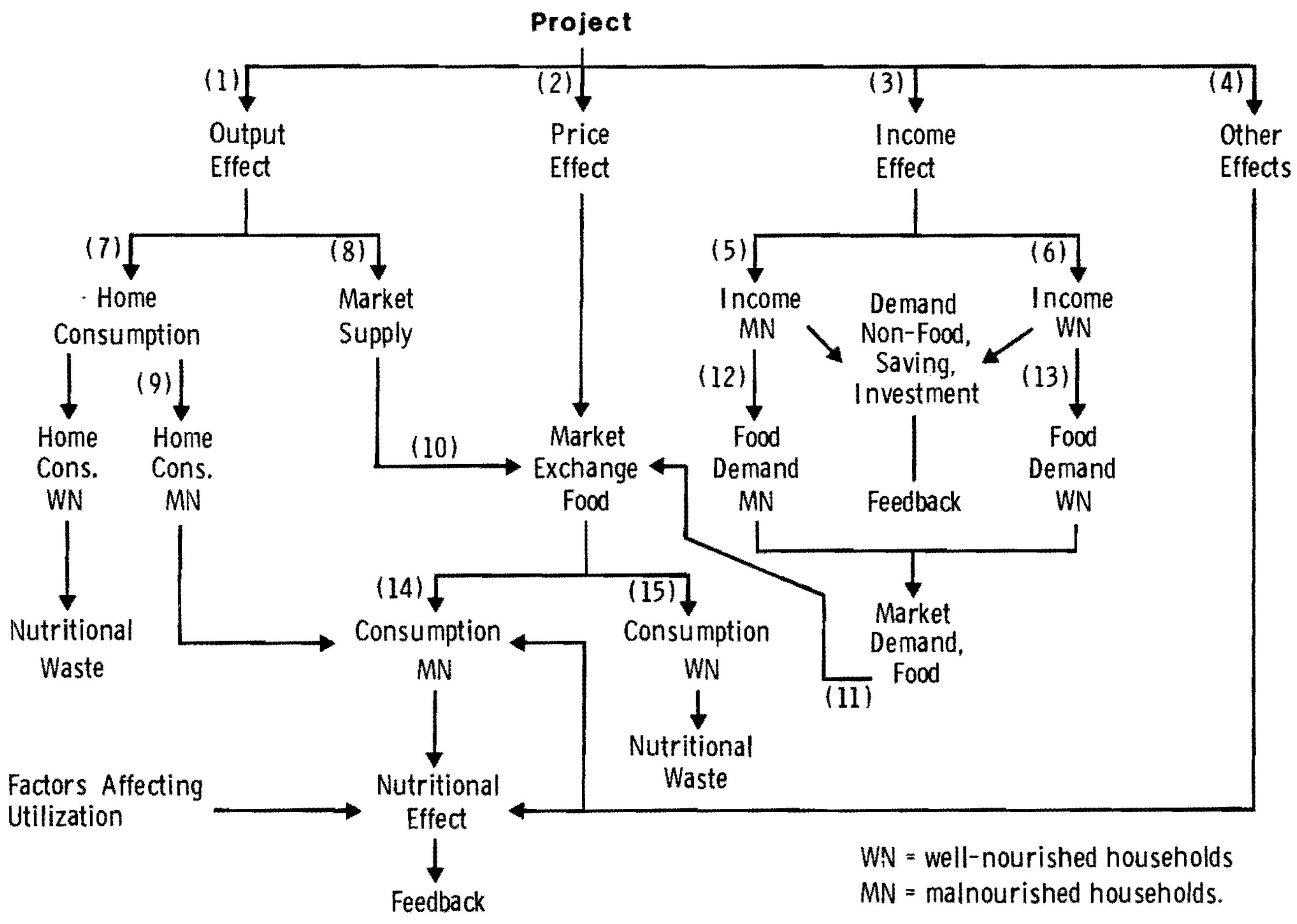
Agricultural production research may influence nutrition through changes in food output, food prices, and incomes. The output effect may be direct, e.g., expanded production or change in the nutritional composition of a commodity towards which the research is aimed, or it may be indirect, e.g., commodity substitution or output effects of input oriented research. The output effect on nutrition may be positive, neutral, or negative. Changes in output are reflected in either home consumption, market supply, or both. Changes in home consumption may or may not affect

nutritional point of view is not how the aggregate output of nutrients is affected but the change in the consumption by malnourished households.

If the change in market supply is sufficiently small not to have any impact on prices or prices are otherwise kept constant, then the nutritional effect of output changes per se is limited to a possible change in home consumption by malnourished households. Consumption by malnourished households obtaining their food through the market exchange will not be affected. This will be the case whether nutrient output is expanded or reduced.

Agricultural research and associated public policies may affect food prices directly, or indirectly through changes in output or incomes. Whether direct or indirect, the price effects

Figure 1. Illustration of Linkages Between Project and Nutritional Effect.



well-nourished, and should be considered in research planning. In the case of most agricultural research, any price effects are likely to be indirect. However, existing or suggested policy measures of various kinds, e.g., price support and foreign trade policies, may, of course, have significant direct price effects. Such effects should be considered in research planning. Agricultural research may have a very significant nutritional impact through changes in incomes of malnourished groups. Low-income farmers, agricultural workers, workers in rural service, and input supply sectors are some of the most obvious potential beneficiaries. Changes in incomes by these groups affect their demand for food which, in turn, alters their competitive position in the market and, as a result, their food consumption. Furthermore, changes in incomes by producers may alter their home consumption.

Income changes among well-nourished groups is also likely to influence food demand, the competitive market position of the various consumer groups and, thus, consumption of well- and malnourished groups. Increasing incomes among well-nourished groups may bid up food prices and reduce consumption among malnourished groups. If prices are kept constant and the market supply is adjusted to avoid market shortages, income changes among well-nourished households will not influence nutrition.

Agricultural research may influence consumption and nutrition in ways other than those mentioned above. In particular, some research may alter the intrahousehold distribution of incomes and household budget control. Furthermore, the demand for time by the various household members may be changed. These and related issues may have significant nutritional implications. Factors influencing the extent to which consumption changes among malnourished households will result in nutritional changes, e.g., health, intrafamily food distribution, and nutrient balance in the diet are, of course, of major importance.

Only the first-round effects have been discussed. This should not be interpreted to mean that agricultural research is expected to have no sustained nutritional effects or that nutritional changes have no impact on future economic growth and equity. On the contrary. By focusing agricultural research and technological change on nutritional and other basic needs as an integral part of economic growth, improvements in human resources and a more equal access to the benefits of growth are facilitated. Furthermore, investments and savings resulting from technological change in agriculture and associated factor and consumption linkages may facilitate limits, only the first-round effects are explicitly considered.

Key Parameters

Figure I illustrates the key relationships and parameters. The relationships were discussed above. Key parameters may be divided into two groups: (1) project-specific, and (2) non-project-specific parameters. Project-specific parameters refer to the output, price, income, and other effects illustrated in Figure I by (1), (2), (3), (4), (5), and (6). Overall direct output and income effects should be considered in research planning irrespective of whether nutrition is an issue or not. However, the effects need to be disaggregated on malnourished and well-nourished groups to be useful for purposes of nutritional assessment. Indirect output effects, e.g., commodity substitution, should be considered in research where they could be expected to have significant nutritional effects. Effects on the seasonal food availability--an issue of considerable importance for nutrition in many cases--should be considered. The impact of research on non-food agricultural commodities on food supply and food prices is also an important issue.

Direct price effects are uncommon and effects on intrahousehold income distribution, budget control, and time allocation may be excessively difficult to estimate. Thus, to incorporate nutritional considerations, output and income effects would ideally be estimated by group, e.g., malnourished farm households, malnourished landless labor, etc. Furthermore, in cases where they appear to be important, attempts should be made to estimate project effects on intrahousehold variables mentioned above.

Other project specific parameters refer to the distribution of the output effect between home consumption and market supply (7), (8), and the resulting change in home consumption by malnourished farm households (9).

Once the market supply for a given commodity has been affected, its impact on market prices is not likely to depend on the particular research project. The same is the case for changes in a particular household's or group's market demand for a particular commodity due to income changes. Thus, parameters needed to estimate the indirect price effects on supply and demand changes (10) and (11), are nonproject specific. Similarly, the relationship between the demand for individual food commodities and incomes of a particular household, i.e., the change in demand caused by a change in incomes, is not a function of the particular project. But the parameters for this relationship may differ groups of interest. Since, as mentioned above, income changes among well-nourished groups may incluence consumption by malnourished households, the analysis must include both well- and malnourished groups (12) and (13).

The relationship between commodity demand and incomes may depend on the intrahousehold distribution of incomes and budget control. Thus, if a project shifts income or budget control from one household member to another, the above relationships and parameters may change. In other words, if greater household budget control is gained by a certain household member, a larger or smaller proportion of incomes or income changes may be spent on food. This implies that the parameters explaining income-food demand relationships must be re-estimated. In such cases, reliance on existing non-project-specific parameters may cause large errors. Projects affecting the role of women in low-income rural households are of particular interest in this respect.

On the basis of estimates of changes in the market prices for foods and changes in the relative competitive position of the various consumer groups, the distribution of the market supply between malnourished and well-nourished groups may be estimated (14) and (15).

It has been assumed but not explicitly stated throughout the above discussion that malnourished households were identified and grouped. This, of course, is not necessarily so. Therefore, the most critical non-project-specific information is that needed to identify households with malnourished members and group these households according to the type of nutritional problem (what and who) and primary causes. These are the groups for which the above disaggregated analyses must be carried out.

The discussion presented in this section on key relationships and parameters may be briefly summarized as follows: Efforts to estimate *ex ante* the nutritional consequences of agricultural research projects should ideally seek answers to the following questions:

1.) What are the nutritional problems; who is short of what and why? The information needed to answer this question is not project specific. Rather, it should be considered as essential background information for all development activities and public policy. Thus, the cost of obtaining and updating such information should not be charged to an individual agricultural research project.

2.) How does the project affect the output of each individual food commodity? Both direct and substitution effects should be considered. For example, how would a Are there complementary measures that are expected to influence food availability?

3.) What proportions of output increases or decreases are expected to be reflected in home consumption by malnourished households and what proportions are expected to be added to or subtracted from market supply?

4.) Is the project expected to change the seasonal food availabilty?

5.) Are expected changes in market supply likely to have an effect on commodity prices? If the answer is affirmative, attemps shuold be made to quantify the the effect. How would such price changes affect future food production and home consumption by malnourished farm households? Such analysis would rely on estimates of the appropriate elasticities by group. These are discussed below.

6.) Is the project likely to have a direct price effect? If the answer is affirmative, attempts should be made to quantify the effect.

7.) How are incomes and costs of the project expected to be distributed among the groups of interest, i.e., identified functional classes of malnourished households (low-income farmers, landless labor, etc.) and well-nourished as a single group?

8.) What are the income and price elasticities for each of the principal food commodities within each of these groups? These estimates are not project specific and should be considered as essential background information. How are the income changes expected to affect the demand for the various food commodities and home consumption?

10.) What is the net effect of changes in supply and demand on commodity prices?

11.) What is the net effect of changes in incomes, prices, and home consumption on food consumption by malnourished households?

12.) Does the project alter existing intrahousehold distribution of incomes, budget control, and food? If the answer is affirmative, efforts should be made to judge how this might affect the income-consumption relationships, the consumption patterns, and the nutritional effects of changing household consumption. Until additional research has been done, only qualitative judgments can be made on this topic.

13.) Is the project expected to affect any of the factors that determine the extent to which changes in consumption by malnourished households will affect nutrition, second-round nutritional effects that should be considered?

Some of the information needed to answer the above questions is nonproject specific, i.e., it need not be obtained for each project. Thus, an effective functional classification of the population, estimates of income, supply and demand elasticities, and descriptions of the market structure are examples of things that--once obtained and periodically updated--may serve for any research and development project, provided an effective disaggregation is performed. In fact, whether the focus is on project specific or non-project-specific parameters, the primary difference between the information needed for assessment of impact on efficiency goals and that needed to assess nutritional effects is the level of disaggregation. As a rule, average estimates for the population as a whole are of little value for the assessment of nutritional consequences.

Obtaining solid quantitative estimates on all the relationships discussed in this section is likely to be excessively resource and time demanding. Surely, beyond a certain point, such efforts would present diminishing returns and attempts to obtain quantitative perfection could result in very low or negative marginal net returns. Thus, short cuts that would provide effective guidelines without requiring excessive amounts of resources and time must be sought.

A Suggested Assessment Approach

Ideally, ex ante assessment would show how selected nutrition indicators such as mortality of selected groups, work capacity, or anthropometric measures would be affected by the project under consideration. However, cost and time considerations, together with unavoidable uncertainties associated with the results of any ex ante assessment approach would undoubtedly point in the direction of an approach considerably less "perfect," yet providing effective--although possibly rough--estimates of nutritional effects of agricultural research projects.

The assessment approach suggested below is a compromise between cost and time considerations and "degree of perfection." It is recommended that further research and testing be undertaken to explore the feasibility of the approach for routine project assessment. The approach attempts to estimate how a given project would affect consumption by households with malnourished members, ignoring intrafamily food distribution.1/ Project impact on intrahousehold distribution of income and budget control, time allocation of individual household members, and seasonal variations in food availability is also ignored in this approach.

in terms of total change in calorie consumption by malnourished households caused by the project.2/ The approach requires quantitative estimates of project impact on the supply and home consumption of each of the food commodities affected and the resulting price changes. It also requires quantitative estimates of project impact on incomes by functional group and the resulting change in consumption. The approach is briefly outlined below.

Development and empirical testing of a model to estimate the output effect on calorie consumption by various income groups is reported elsewhere (Pinstrup-Andersen, Londono, and Hoover, 1976). Basically, the model estimates (1) how an increase in the supply of each of a number of food commodities is distributed among income strata, (2) the corresponding adjustments in the consumption of all foods, and (3) the resulting impact on calorie and protein consumption by income stratum. A model to estimate the income effect has also been developed and empirically tested (Pinstrup-Andersen and Caicedo, 1978). This model estimates how calorie and protein consumption by various income strata is affected by changes in stratum incomes.

Thus, on the basis of expected impact of a project on commodity supply, home consumption, and incomes by the various groups of interest, the models may be combined to provide an estimate of the total change in calorie and protein consumption by malnourished households. Together with estimates of project costs, such a measure may provide useful guidelines for project design, if improved nutrition is a major goal. Using sensitivity analysis for alternative project elements and designs, the cost-effectiveness of such alternatives may be estimated at the margin, e.g., the cost (in terms of project benefits foregone or resource costs) of improving the calorie intake by target households by a certain amount.

Thus, the primary utility of the approach for project design relates to the choice among alternative projects or project designs. Suppose that a given project modification results in an expected reduction in net economic benefits from the project of x dollars while expected calorie consumption among households with calorie-deficient members increases by y calories. The cost of expanding the calorie consumption by one calorie is then x/y. This ratio may be compared to the least expensive alternative way to expand calorie consumption. One decision rule might then be to accept the project modification only if the expansion in the calorie consumption cannot be obtained at lower cost by some alternative means. Using this approach as a guideline for (1) choice among projects, (2) project not ignore more cost-effective alternatives for reaching these goals.

While elements of the approach presented above have been developed and empirically tested, the approach has not been tested in its totality. Therefore, it is important that testing and adaptation of the approach be performed before it is introduced into routine project assessment. Such testing and adaptation is currently being planned by IFPRI and the World Bank.

Needs for Additional Research

There is an urgent need for the development and testing of assessment approaches such as that mentioned above, which could be applied within reasonable resource and time constraints. While this in itself would be a major research undertaking, additional research is needed to facilitate ex ante assessment of consumption and nutrition effects of agricultural research and other development efforts. In particular, additional research and testing are needed on three topics:

1.) Development and testing of workable methods to estimate or approximate price elasticities of demand by food commodity and functional group. Price elasticity estimates by income stratum or functional group are critical to the kind of assessment suggested here. Yet, disaggregated time series data are very scarce and currently used methods for estimating price elasticities from cross-sectional data are not acceptable when applied at the individual commodity level. Innovative work in this area combined with procedures for collection of the appropriate time series data might have a high payoff.

2.) Research to improve our understanding of the consumption and production decisions made by semisubsistence rural households with particular emphasis on: (a) the interaction between the two, (b) the effect of changes in intrahousehold distribution of income control and time allocation on food consumption by individual household members, (c) the effect of production and price risks and seasonal variation in food availability on consumption and nutrition, and (d) ex post evaluation of the consumption and nutrition effects of technological change within the semisubsistence rural household. Current knowledge on these issues is grossly deficient for ex ante assessment of the consumption and nutrition effects of alternative research and technology for small farm agriculture. Thus, until additional information is obtained, expected consumption and amount of research is underway on some of these issues, particularly the question of time allocation.

3.) Ex post evaluation of the consumption and nutrition effects of technological change in selected areas and for selected commodities. Findings from ex post evaluations are likely to be useful for the preparation of ex ante assessment. Furthermore, such findings would provide guidelines for the design of research and technology to be pursued, even in the absence of formal ex ante assessment. They may also assist in the design of public policies and strategies for institutional change. In particular, the findings would be useful for the design of public policy measures aimed at facilitating desirable consumption/nutrition effects and correcting or compensating for undesirable ones.

Notes

1/If the necessary data are available, consumption by malnourished members of the household may be substituted for household consumption. This would clearly improve the approach but also increase costs.

2/The effect on the consumption of other nutrients, e.g., protein, may also be estimated.

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SOCIAL OBJECTIVE FUNCTIONS IN AGRICULTURAL RESEARCH

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Between 1930 and 1976, the number of farms in the United States declined by just over 50%.1/ Other changes accompanying this decline were, for example, changes in the location of production, composition of output, the size of the farm and the number of farmworkers. Between 1960-1975, U.S. farm employment fell from around 7 million to 4.4 million. During that same period, the asset-per-farmworker ratio rose to over $100,000, a rise of over 500%.

During the 1965-1976 period, real U.S. GDP rose 38%.2/ Output of the agricultural sector rose by 9% in real terms, 216% in current prices. The share of GDP originating in the agricultural sector fell from 3% to 2%. Such changes in the structure and composition of U.S. farming are both a determinant of and a result of the changes in U.S. GDP. As one of its components it contributes a portion of that output. Prosperity in the agricultural sector, therefore, contributes to overall prosperity. As a user of inputs produced in the nonfarm sector, farming productivity is affected as much by the availability of such inputs as well as by the managerial skills of the farmer.

The preceding is purely descriptive; the concern of this paper is with the normative. A further concern of this paper is the attempt to develop a means, *ex ante*, to judge the desirability of such changes in the future, and of the policies which give rise to them, rather than with making *ex post* judgments on the past. Just as the building of the pyramids did little to raise the wellbeing of their builders, so there is a danger that research designed to further increase agricultural output and productivity may be equally guilty of neglect of human values.

An appropriate starting point in the examination of values in economics is with prices. To certain economists, such prices appear to perform the role of incorporating all necessary value judgments into the domain of economics. The simplest expression of such a belief is in the price = marginal cost = marginal utility rule, P = MC = MU. From this, we see that a price is merely a counting device, or point on a scale called money, whose basic unit, at least in the United States is $1. As such, it is free of all but the purest of intentions, namely an accounting device. Only when it appears in conjunction with the above equilibrium conditions can more be said.

In a general equilibrium framework the above conditions may be restated as a Pareto Optimal state. However, although the achievement of such a state may be unimpeachable on technical grounds, it is but one of numerous Pareto Optimal points, each one a function of a certain initial income and asset distribution:

> A competitive equilibrium, even if it is also a Pareto Optimum, may involve a more unequal distribution of income than is regarded as desirable from a social point of view. The concept of a Pareto Optimum is *insensitive* to this consideration, and in that respect the term 'optimum' is a misnomer (Koopmans, 1957).

Consequently, the selection of any one such state as being preferable over others requires the existence of some form of preference or welfare function. As this paper is dealing with the United States and not just, for example, the wellbeing of the participants in this conference, I shall refer to this as a social welfare function.

I have referred to these basic economic concepts almost as a parable, for when we make the leap from pure theory to agricultural policy, it is well to have this parable retold. For example, I have the impression that in some eyes research is neutral as to its impacts on such states or not responsible for determining such social outcomes. Either they are the product of a Panglossian world which assures us that what is, is for the best, or they are outcomes of a benign, or perhaps neutral lottery. Yet, land is retired, crop prices guaranteed, export markets subsidized, and research channeled into some areas, not others, all of which are conscious human actions and all of which are determinants of the level and distribution of economic wellbeing.

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decline in SMYs devoted to agricultural research between 1966-1971. In some areas the numbers increased, in others they declined. In weed, insect, and disease control, they fell. In fruit and vegetable mechanization, they rose, as well as in fruit and crop production, In what sense can it be said that the results of these changes were either neutral or socially optimal? What form of social welfare function, either implicit or explicit, gave rise to these changes? Was there a split between the implicit and the explicit or between the assumed and the extant? It is my contention that only by answering such questions can we begin to judge the benefits to agricultural research.

Although I use the word "function", I am not proposing its use in the strict mathematical sense, which gives a unique ordering of states of wellbeing for all possible values of its arguments. Perhaps Sen's Social Decision Rule may be more appropriate, but here I avoid such taxonomic questions (Sen, 1970). Thus, for example, if we use the compensation principle whereby we judge a change as acceptable if the gains to the winner could potentially compensate the losses to the loser, this would be one form of such a rule or function.

In numerous economic changes, which certainly include those brought about by much agricultural research, we find that prices do not adequately measure costs and benefits due to the nonmarginal character of those changes. Here we have the familiar problem of index numbers, the problem of changing the weights, namely prices, by which we add the physical inputs and outputs. We would also consider the amount of consumer and producer surplus generated, in order to determine the total costs and benefits of policy induced changes.

To recapitulate, we would need to modify our reliance on GNP data which makes no value judgments on distributional matters: \$1 = \$1 = \$1, irrespective of who receives it. We would, therefore, need to make explicit judgments on income distribution, as well as make corrections for nonmarginal economic changes, as well as for cases where $P \neq MC$ for other reasons, such as market imperfections.

If we achieved this economic purity, would we have achieved the challenge I am making to the participants? Unfortunately not, for many outputs of an economic system are not priced, and therefore will not be captured by our improved cost/benefit calculus unless we also include them. I shall refer to these outputs as externalities, to include public goods as a special case.

I would argue that externalities are just as pervasive in agriculture as they are in other sectors. It is not my intention to be encyclopedic, but merely to suggest a few examples to illustrate the problem.

Most textbook examples deal with the spillover type of externality; the acid rain effect of a smokestack on neighborhood structures; the effect of a dam on the value of land downstream; the provision of fruit trees benefiting the beekeeper. These examples combine both pecuniary and technological externalities which I shall not distinguish in this paper.

Let me begin with the bête noir agricultural research, the use of DES in cattle fattening, and combine this with another 'D', the use of DDT in crop production. Both are recognized to have severe external effects. From a social point of view, the costs and benefits of their use may diverge from the private evaluation.

For my second group, let me again take two examples, the production of gasohol and the mechanization of crop production and harvesting. Current gasohol production research proposals seem to point to two alternative systems. One, operating on a small scale, would enable farmers to convert grain to alcohol in stills sited on the farm. The other envisages one commercial still producing at a level which would probably produce the entire U.S. output. There appears to be a considerable difference in the efficiency of the two systems. On the other hand, there may also be considerable equity implications of the final choice, and therefore a need to consider the equity/efficiency trade-off. In this example, there is an awareness of the problem and of the possible social costs, but in the mechanization problem we typically examine the costs ex post. The social costs of mechanization in cotton and tomato picking were probably not considered at the time such developments were introduced. But the farmers in California who are threatening legal action against their university for financing the research which gave rise to these changes are essentially asking this question: "What type of social welfare function was used which judged that the public funds used to finance this research had a greater social rate of return in this use than in, for example, insect control?" Or to state the problem on an even more basic level: "Which social welfare function was used which judged the gains to the large commercial grower to outweigh the costs incurred by the small producer?"

I am not, for one moment, arguing that the entire process of economic development has had a net social cost. But I am arguing that, just as in the first set of problems, such distributional problems cannot be assumed away. In my third externalities in the abandoned small towns and lost jobs. The problems which arise in this context have been well discussed in Benefits and Burdens of Rural Development (C.A.R.D., 1970) and in Focus on Iowa (C.A.R.D., 1972), but I raise the issue here as an example of some of the externalities associated with the changes in scale and input mix described in the introduction to this paper.

I now turn to consider the consequences of neglecting the importance of such externalities. The first one, although merely a definitional consequence, is that market prices cannot be used as socially optimal indicators of costs and benefits. The second consequence is a tendency to generate hostility to the cause of the externality on the part of those bearing the external cost. I would be hesitant to draw a causal connection between such hostility and the decline in SMYs referred to above, but at the least such objections do not support an expanded research program.

The third consequence is frequently encountered, that of reaction rather than action. Environmental impact statements and lengthy legal proceedings would not disappear if the concerns of this paper were adequately recognized, but I have a strong feeling that an anticipation of such issues, an attempt to incorporate them into the early decisionmaking or the involvement of various parties affected by such decisions, these would be steps to reduce the costs of reaction. Moreover, I am also suggesting that such considerations also be incorporated into the research design and development phase.

My concerns so far have been with what should be done, but not how. I am unaware of any social objective function lying on the shelf ready to be used, but at the same time I am not daunted by the impossibility theorem that no such function can exist. The proposal which follows is therefore not to be seen as an attempt to provide the social welfare function, but a less ambitious attempt to incorporate the above social concerns into agricultural planning.

Planning Proposal

The proposal considers the experiment station director as responsible for maximizing some objective function by allocating a given budget, subject to various additional constraints as yet undetermined. Given the transformation from budget to SMYs, the latter takes on the role of the main constraint. The maximand consists of outputs which are changes in knowledge, both embodied and disembodied.

tinuum in order to determine the arguments in the function; (3) the structure of the matrix of research activities; (4) the number of arguments in the objective function; and (5) the form of the function, and therefore, the form of aggregation over individuals and over inputs.

I consider the proposal as a guide for those involved in the decisionmaking process, the exact specification to be determined in the context of the specific circumstances. It is based on the work of Dalkey (1972) and Van Gigch (1974). Dalkey's work, at UCLA and the Rand Corporation, has become known as the Delphi--"Know Thyself"--experiments. These were undertaken by Dalkey and others to test whether or not groups were capable of making group judgments, on both factual matters and on value judgments. Says Dalkey: "...as the studies in the following chapters show, individuals can make numerical judgments concerning the relative importance of basic life values, and these numbers are not capricious" (1972, p. 7).

The Delphi technique, as originally devised, was concerned with small group decisionmaking. This has been used both to obtain group expert opinion as well as to obtain a list of variables with their respective values which are considered the most important quality-of-life variables (Dalkey, 1972). Underlying this approach are three conditions: (1) reasonable distributions, (2) group reliability, (3) change, and convergence on iteration with feedback.

Work on the Delphi method has been further developed by Turoff who, by examining the different uses of the Delphi approach, has pointed out its appropriateness in different circumstances and the modifications these require to the general procedural principles (Turoff, 1975). Thus, in this respect, it is essential to distinguish between two aspects of a Delphi analysis.

(a) Defining the structure of the problem, the impacts and consequences of various outcomes and activities. As examples of this type of work, Turoff refers to Longhurst's work in analyzing the effects of pre/post natal care on I.Q. Given the lack of a suitable model, two Delphi groups were established to determine the relevant components to include in the study, and to assess the results of various programs. Jilson (1975) refers to this aspect of the work as the development of a transition matrix. Economists refer to this as a structural model.

(b) The second aspect is the evaluation of various programs in terms of objectives or goals, these, in turn, being either the product of a

It is essential in any Delphi procedure that these two aspects be clearly distinguished. Failure to do so will result in a confusion between what is feasible and what is desirable, or, in Turoff's words, in disagreements which may arise out of differences in uncertainty or information and differences in self-interest.

Although the purpose of this study is to determine the set of weights to be used in policy evaluation, it will be argued that in all but a purely formal sense such an exercise also requires a knowledge of the structural model. Two reasons may be given in defense of this argument. The first, as just mentioned, rests on the need to be able to distinguish between the goals and constraints of a problem. The second arises from the need to determine what the outputs of such a system are together with the need to specify goals at a common level on a means-ends continuum.

For these reasons, this proposal considers establishing two Delphi groups. The first is known as a Policy Delphi (PD), which describes the structure of the matrix of research inputs and outputs. The second, the Goals Delphi (GD), is designed to evaluate the desirability of various research outcomes, or alternative budget allocations.

Goals Delphi Alternatives

The objective of this section will be to review alternative procedures the goals Delphi might adopt to assist in improving station budget decisions. Some attempt will be made to examine various approaches found in a rather diverse body of literature, in order to understand the differences in design and circumstances of these approaches.

The first distinction to be drawn is between formal or normative and descriptive or institutional procedures. The latter are illustrated by Simon's "Carnegie" method in which the decisionmaking process itself is an essential ingredient for interpreting the consequences or outcomes of organizational decisions (McFadden, 1975). The former, which account for the bulk of such models in economics and management science, can be described as attempts to adapt the utility maximization concepts of individual choice theory to an organization, group, or bureaucracy.

Within this second group are to be found a variety of techniques for both understanding organizational behavior and providing optimal decision rules and guidelines. The first type will be referred to as an optimum budget allocation procedure. This is illustrated by the work of the priority approach (1975). Kaldor's procedure was based on the principle of an optimal allocation of a given budget being reached where the marginal return to a dollar was equal from all possible activities. In Kaldor's development of this principle, a panel was to be given the opportunity to transfer funding in such a way that when no further reallocation was deemed desirable, such an optimum was reached.

Where market prices exist, net-present-value and rate-of-return techniques are an approximation to this approach, allowing for the fact that the size of certain projects may not be sufficiently flexible to permit a common return or benefit at the margin. Instead, projects may be ranked, with the marginal project being defined as the one which just exhausts the budget as one moves down the list of projects in decreasing order of benefit.

A second class of techniques requires estimates of demand functions, parameters being specified either as unit-dependent or as elasticities. As an example of the former, Deacon and Shapiro (1975) estimate a demand function for both environmental quality and rapid transit by means of a logit analysis of voting patterns in California. Using more familiar regression analysis, Bergstrom and Goodman (1973) estimate, among others, income and tax share (price) elasticities for police, parks, and general municipal activities.

Given that a demand function is based on the principle of utility maximization, any point on that function is regarded as an optimum. However, where prices are not known even the existence of such a function will not be of any assistance in budget allocation.

The third approach, one which appears to have dominated studies of organizational behavior, attempts to obtain either the weights or a complete specification of a preference function itself.

A representative selection of the revealed preference approach to developing such knowledge can be found in the work of McFadden (1975), Friedlaender (1973), Hori (1975), and Rausser and Freebairn (1974). The basic citicism of such work, in addition to that of Makin (1976) concerning identification problems, is to be found in Johansen's outstanding survey (1974). Where a demand function cannot be estimated due to inadequate data or lack of time to test consumer behavior, it is necessary to attempt to measure the utility function directly. However, this is precisely the situation in which it is most difficult to obtain such a function.

in two further ways. One, followed by Frisch (1976) uses a direct interview technique to build up the shape of a preference function. The other, closely related to it, consists of more experimental attempts to obtain such preferences by offering varying commodity bundles and recording choices made (MacCrimmon and Toda, 1969; Rousseas and Hart, 1951).

Despite these differences, these last two methods exhibit sufficient similarities to be subject to several of the criticisms raised by Wallis and Friedman (1942) against such methods, these being based on the artificiality or experimental nature of such attempts. However, it would appear that these criticisms are themselves more appropriately concerned not with the attempt to study choices and preferences, but with the attempt to completely specify the range and shape of the preference function. If this degree of exactness is not required then the criticisms themselves are weakened.

The work of Geoffrion, Dyer and Feinberg (1972) is proposed here as the basis for the policy Delphi for this reason. This method combines both the normative and descriptive branches described above, enhancing the applicability of the proposal. For, as noted by Zimmerman (1977): "Without any understanding of the environment, including the institutional framework, normative models are likely to be exercises in applied mathematics." Decision information systems, on the other hand, by allowing for feedback and sensitivity testing permit solutions to be obtained in situations in which the direct quantification of multiple criteria leaves much to be desired (Baker and Freeland, 1975).

We may also note the comments of Fox (1972) in the context of a similar problem, that of resource allocation in a university department, in which "The idea of an objective function to be optimized would probably improve the decisions of the Chairman and Dean, whether or not formal computations were used."

An Interactive Approach to Multi-Criterion Optimization

Following the work of Geoffrion et al (1972), we review a procedure for the Goals Delphi to follow, as described in the following steps:

(a) An initial point is defined which measures the level or rate of activity in either dollar terms or in SMYs. Note that these measures are the sum of inputs in the means-ends hierarchy up to that point. Where, as is most rule to apportion these inputs will be necessary, to be determined by the Policy Delphi.

(b) A set of weights, expressing the trade-off between all pairs of activities, to be determined by the Goals Delphi. In an ordinal specification these weights may be specified as relative to some arbitrarily chosen reference criterion, or numeraire, say activity 1. At this stage, it is not necessary to constrain the range within which these weights are valid. We also note that if, for example, w_2/w_1 and w_2/w_3 are known, yet difficulty exists in determining w_3/w_1 directly, we can obtain this from $\frac{w_2}{w_1} \cdot \frac{w_3}{w_2}$.

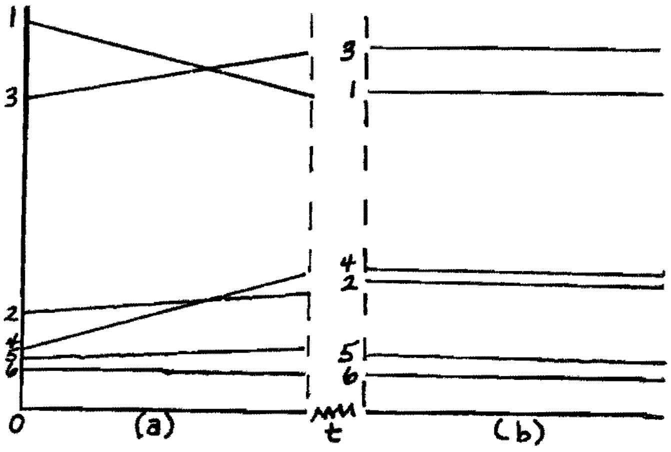
The technical basis for this approach is contained in Appendix 1.

(c) Given the weights above, the procedure requires a solution to the direction-finding problem which maximizes the preference function given those weights (see Appendix, equation 2'). The levels of each activity, some rising, some falling, will vary with the size of the step or range over which the relative weights are allowed to hold. Thus, for example:

Figure 1

Activity/Title	S.M.Y.s	A	B
1. Crops	300	1	1
2. Extension	30	4/15	5/15
3. Livestock	200	2/3	5/6
4. Soils	60	1/5	4/15
5. Nutrition	50	1/6	1/4
6. Forestry	40	2/15	2/15

A = existing trade-off.
B = revised references.
(a) = solution using B.
(b) = optimal solution after k^{th} revision.



timal point being selected. This is done by determining t, the size of the step, which is here given as .75. In selecting t the Goals Delphi is selecting a most preferred point at that level of activities.

(e) The procedure is then run through a second iteration. The Goals Delphi selects a new set of relative weights with the solution at (d) as the new reference point. Given that the procedure is searching out an optimum we would expect less changes in relative weights at each round of the iterative procedure until an optimum is reached. At such a stage, if we were to repeat Figure 1 we would find the lines drawn to be virtually horizontal.

Several comments may be made to conclude this section. As will be evident from the above description, the success of the procedure requires a monitor who is fully conversant with the procedure. Secondly, the interaction between goals and results is an essential part of the procedure providing interaction and feedback to the participants. In this lies its advantage over more abstract attempts to formulate goals. While the latter may be desirable, as normative guides they are less useful as descriptive aids to solving problems of resource allocation.

Thirdly, by not requiring a complete specification of an entire preference function, the question of the validity of the range over which the weights hold does not arise.

Finally, it should be noted that no *a priori* restrictions are placed on the aggregation of individual preferences within the Goals Delphi. This applies to both the individual weights and the method by which these are summed to provide group preferences. A number of decision models (Bacharach, 1975; Keeney and Kirkwood, 1975; Freimer and Yu, 1976) tend to be guilty of what Van den Bogaard and Versluis (1960) describe as the assumed Law of the Medes and Persians that the scaling constant, λ, to aggregate individual preferences, must be linear. Nor does such an approach rely on minimizing sums of squares or R^2 coefficients to determine consensus or agreement (Ford *et al*, 1978). Nor does it make the mistake, as shown by Haefele (1973), of assuming the arithmetic mean of the individual optimal decisions is the socially optimal one (Bogaard and Versluis, 1960).

Composition of the Delphi Groups

(1) *Policy Delphi*. The two alternatives one may consider are:
(a) one representative from each scientific discipline involved in station research, and (b) the basis for representation to be weighted by discipline as a constituency, with the initial distribution of power weighted by relative SMYs. However, the purpose of the Policy Delphi is to be analytical, providing input and advice, not to be representative. Accordingly, (a) is suggested.

(2) *Goals Delphi*. Here we may consider three bases for selection: (a) the station director selects to maximize the long-run funding of the station, (b) one representative from each interest group affected by station research, as discussed in section IV 3. (c) territorial-based representation, for example, one representative per state legislative district.
Proposals (a) and (b) are obviously closely related, in that one way of maximizing long-run station funding is to select representatives from economic groups receiving the greatest economic benefit and overlooking those whose economic standing may be harmed. As such both are examples of dollar representation referred to above. However, insofar as this proposal is an attempt to break away from the inherent conservatism of such a structure, this would be an unacceptable basis for representation. It would, for example, violate Tinbergen's "principle of the fundamental equality of man" (1972). As Haefele (1973) has written:

> "The dollar vote is of obvious usefulness in corporate management and similar concerns where dollars are at risk. When lives, tastes and wills are at issue, the dollar vote has little to recommend it."

While the principle of territorial representation has much to commend it, the practice of establishing such a group may pose certain difficulties. Not the least of these is that establishing a Delphi group in this situation is not an attempt to duplicate a legislature but to establish a smaller group following legislative principles in reaching decisions.

To select such a small group, we may consider using some random sampling procedure such that the composition of the sample is designed to reflect the underlying population. For example, the state of Iowa could be split into n-regions, with each region having an equal likelihood of being selected. By random selection, a sample of representatives could be drawn whose decisions would be taken as representative of the larger constituency. No simple procedural rule lies on a shelf waiting to be used in circumstances such as these, but the problem is not insoluble.

Concluding Remarks

My hope is that I have indicated the possibilities for incorporating social concerns into experiment station budgeting. Of course, I hope that the word challenge not be misconstrued as a threat to any particular discipline. The benefits of possibly larger research finding, contingent on the improvements this proposal makes over current practices, could well accrue to all parties.

Footnotes

1/Data from Sundquist, 1977.

2/Data from O.E.C.D., 1976.

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Appendix 1

Mathematical Specification of Model

Following Geoffrion, et al (1972), we have:

(1) $\text{Max } U[f_1(x), f_2(x), \ldots f_r(x)], \quad \text{s.t. } x \varepsilon X$

where: x is the vector of decision variables,
f_i are the outputs associated with x,
U is the decisionmaker's utility function.

To solve the above problem in an iterative interactive approach of k steps, set k=1, choose the initial level of station activities as x_1, and solve for an optimal solution to y_1, the direction inwhich the r functions proceed in Step 1.

(2) $\text{Max}_{y \varepsilon X} \quad \nabla_x U[f_1(x_k), \ldots , f_r(x_k)] \cdot y$

Setting $d_k = y_k - x_k$.

(3) $\text{Max}_{0 \leq t \leq 1} \quad U[f_1(x_k + td_k) + \ldots, f_r(x_k + td_k)].$

(4) Setting $x_{k+1} = x_k \text{ T } t_k d_k$, $k = k+1$, the procedure is iterated back to step 1. The size of t maximizes the utility of the decision-maker.

As an approximation to U, using the chain rule, (2) becomes

(2') $\text{Max}_{y \varepsilon X} \sum_{i=1}^{r} w_i^k \nabla_x f_i(x_k) \cdot y$

where w_i^k gives the (ordinal) trade-off between

$$(\partial U/\partial f_i)^k / (\partial U/\partial f_1)^k \qquad i = 1 \ldots, r,$$

with x_1 being chosen, arbitrarily, as the reference, or numeraire.

The iteractive nature of the approach is demonstrated in step (3), where the solution to (2) given the w_i^k is generated for the unit range $0 \leq t \leq 1$. The decision maker then selects a value for t which in turn determines x_k, permitting x_{k+1} to be determined and so on.

Using the procedures discussed in the text, we see that the Goals Delphi is responsible for the determination of w_i^k. The Policy Delphi is responsible for the specification of f(x), and the monitor is responsible for solving for the solution to (1) at each step.

YIELD INFORMATION NEEDED FOR THE ANALYSIS OF CROP IMPROVEMENT RESEARCH

Dana G. Dalrymple*

Introduction

The purpose of developing new crop technology is generally to increase yields per unit of land and to reduce costs per unit of product. A rather elaborate methodology has been developed to measure the rates of return from such investments, principally involving ex post analysis. Improvements to this methodology are continually being suggested.1/ Yet much of this sophisticated methodology is built on a rather limited statistical base--particularly when it comes to the actual measurement of the effect of the technology on yields.

Some of these yield measurement problems, such as the difficulties in isolating the yield effect of a specific technology when it is part of a package of interacting technologies, have long been recognized. The influence of weather and other factors must, of course, also be considered. Production functions have been an important tool in sorting out the roles of these factors.

But relatively little methodological attention seems to have been given to the basic yield data themselves. These are of critical importance in index number analysis. Just how good are the available statistics? What are their advantages? What are their limitations? What alternative sources are available? Could existing data be utilized in a better way? What additional data might be gathered?

As one who has given considerable attention over the past decade to the collection of area data on wheat and rice, 2/ I must confess to have largely neglected these questions. Yet to judge from the literature, I am not alone. Perhaps the time has come to balance improvements in methodology with concern for the basic data. The purpose of this paper is simply to highlight the issue and to try to stimulate others to explore the matter further.

Sources of Yield Data

Despite widespread concern with yields, a rather limited array of yield data are usually available. These may be divided into those obtained at the experimental level and/or at the farm level. I suspect that most agricultural economists are considerably less familiar with the former than the latter.

Experimental Yields

These are, of course, the yield levels obtained on the experiment station or field stations. These trials are generally closely controlled to exclude or minimize the effect of other variables. But the process of doing so means that they cover a rather limited area and perhaps a limited period of time. As far as they go, however, they provide an excellent idea of the potential for the improved technology.

This initial work is often followed by more substantial testing in regional trials throughout the nation3/ and sometimes at the international level.4/ Again, the actual area planted may be rather small, but the number of replications under different conditions is increased substantially. The temporal dimension is also enlarged.

The result of this extensive testing process is that by the time a variety is released, the breeder has a fairly good idea of its wider yield potential. The yield advantage is often mentioned in the release announcement.

While this sort of data is well known to crop scientists, I suspect it is not well known by many agricultural economists. Moreover, it is often not readily available and is classified as preliminary. The introduction to one annual summary, basically a mimeograph, states that it

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> "...containing preliminary data which have not been sufficiently confirmed to justify general release; interpretations may be modified with additional experimentation. Confirmed results will be published through established channels. The report is primarily a tool for use of cooperators and their official staff..."5/

Confirmed results, however, are often not presented in the same comprehensive framework.6/

While agronomists go on to use such trial data in making yield comparisons.7/ it appears that the economist is seldom, if ever involved. And by himself, the economist may have some difficulty in analyzing the data. He will need to know something about how the tests were conducted and a fair amount about the varieties themselves (some may be listed only under test numbers). The result is, I suspect, that very few agricultural economists ever follow the experimental yield data very closely and/or make use of them (the paper by Orazem in this volume is one exception.

Average Farm Yields

Most economists simply utilize the data issued by most state or federal governments on average yield levels at the farm level. Published average farm yields have several undeniable advantages for the agricultural economist. They are relatively available. They are standardized. They apply to a broad area. They are costless or virtually so. And they

The disadvantages, of course, center about the highly aggregative nature of the statistics. All varieties are included; data on the specific variety is seldom included. The influence of differing cultural practices and cropping systems is not delineated. Yet, yield levels reflect the influence of many biological, economic, and institutional forces beyond the individual technology. These factors can make it quite difficult to sort out the "pure" effect of the technology.

There is, of course, a potential additional source: special farm surveys. If these are done only once in a limited area on a recall basis, there are substantial limitations to the data. But if they are well organized and carried on for a period of years over a wide geographic area, they may be of considerable validity. But how many economists outside of the international agricultural research centers are involved in such ventures?

In any case, it is widely recognized that is certainly not always the case, and in some instances, the situation may be reversed). The reasons, of course, may be many, ranging from environmental to cultural and management conditions. Even where many of these factors are standardized, there may still be yield differences favoring the experimental plot.8/ The yield limitations faced by the farmer have recently been studied in considerable breadth and depth in the case of rice in Asia.9/ How have these yield differences been handled in evaluations of crop research?

Examples of Approaches

It would be instructive to examine most or all of the studies that have been done on the rate of research to determine how the estimate of increased yields was determined (except where derived from production functions). I have not had the opportunity to do so. But a few examples may be cited to show something of the range of approaches.

Griliches, in his pathbreaking study on hybrid corn, simply assumed a figure of 15%, based on industry estimates ranging from 15 to 22%.10/ Three such estimates were cited, dating from 1940, 1942, and 1952. It is uncertain to what degree these sources made use of primary data. In this case, however, the hybrid varieties had been in use long enough so that a rather clear perception of their yields advantages may have emerged. Still, I can't help but wonder about them.

A subsequent study of cotton research in Sao Paulo, Brazil, by Ayer and Schuh was more precise in its yield estimates.11/ The estimates were derived from carefully controlled test plot experiments conducted by the government from 1924 to 1967. The increments were divided into five periods and varied somewhat. The internal rate of return was also calculated with yields 10% above and 10% below these estimates, with little change in the result. When the use of such estimates was criticized by Saylor as being too high in terms of farm level results, 12/ Ayer and Schuh noted that (1) after 1936 the test plot comparisons were extended to all major producing regions and were also initiated on privately owned and operated farms which were contracted by the state for seed multiplication, (2) fertilizer and insecticide applications were set at approximately the state average rather than output-maximizing levels, and (3) each variety was entered for several years.13/

Saylor proposed utilizing changes in average state yields from a base period.14/ This approach was in turn criticized by Ayer and Schuh on three counts: (1) the base period data were sharp change in relative product prices during the period. In short, they suggested that Saylor's computations were not based on data which adequately reflected differences in productivity that resulted from varietal change.15/ Saylor's approach was later also criticized by Musalem 16/ because (1) it took into account the full adjustment process that followed after the initial shock of pure technological innovation, and (2) it involved a shift parameter that includes all factors affecting yields. 17/

A third study was conducted of several crops in Colombia by Hertford and others.18/ In the case of rice, their yield levels were based on 665 individual field trials conducted by the Colombian Agricultural Institute (ICA) during the 1957-71 period.19/ The trials, *pruebas regionales*, were conducted on commercial farms; farmers ran the trials but materials and instructions were provided by ICA. Similar data were obtained for cotton (499 observations from 1953-72) and wheat (1,016 observations from 73).20/ Production functions were used to sort out the influence of other factors influencing yields. While the basic data summarized by Hertford, *et. al.* may have had some limitations 21/ they represent a promising extension of the approach taken by Ayer and Schuh.

In my own studies of high-yielding varieties in Asia, I have found it quite difficult to obtain reliable estimates of the varietal effect under comparable field conditions. In one case, I used the best estimates I could find and then subjected them to a crude sensitivity analysis. 22/ In a recent study of wheat and rice in the United States I summarized a number of experimental results, but didn't find anything quite comparable to the field trial data utilized by Hertford, *et. al.*23/ Such data may, however, exist somewhere.

Of the various approaches, the use of farm trial data would appear particularly promising. What do we know in a general sense about such trials?

Farm Trials

Although one might expect that farm trials of the sort conducted in Colombia have long been a normal part of the testing process for new varieties, this does not appear to be the case. I have found a few references which provide suggestions for farmers wishing to conduct their own trials 24/, but essentially relating to farm trials conducted under the supervision of the research organization. The international centers have had some involvement with such trials; and while several of their publi-

seems to have been written down.

Sanders and Lynam at the International Center for Tropical Agriculture (CIAT) in Colombia have utilized such trials for beans and cassava and have recently commented briefly on their experiences.26/ They note that farm trials differ from normal experimental trials in that with the farm trials:

*inputs and management are at relatively normal levels (rather than at the high levels often used in experimental trials to maximize the treatment effect);

*little effort is made to separate individual input or factor effects;

*the variance within treatments between farms is a vital measure or indicator of the other farm level research problems or factors influencing technology; and

* a large number of trials is needed.

The principal limitations of farm trials are their site-, time-, and variety-specific nature. And some cost and supervisory time is involved. From the economist's point of view, three major questions need to be answered:

1. Are there significant differences between the treatments?
2. Is the new technology more profitable than farmers' practices?
3. Does the new technology fit into the farmers' production system?

In the process of answering these vital questions, the economist (and the trials) can provide important feedback to the scientists.

Farm trials are thus a form of *ex ante* analysis that preceeds commercial adoption. Even though they are more indicative of what may happen at the farm level than the experimental work, they may still not be fully representative because of the supervision of the scientists and the likely above-average nature of the farmers involved. This may be difficult to accomplish if the *ex ante* character of the trials is to be maintained. One might think of conducting farm surveys of early adopters, but these necessarily would involve a time lag and again the farmers involved may not be typical. This problem merits further study.

In evaluating trials it should be realized that in addition to providing feedback to the scientists, they may be of considerable educational value in disseminating the technology among farmers. In fact, they are only one small step away from farm demonstrations--long a basic technique in extension or outreach work.27/

Farm trials, however, may not be needed in every case. In areas where research has long been carried out and there is a well-known relamay also be of less immediate need. There is unquestionably a cost connected with farm trials and this must be balanced against the returns from the process.

On balance, farm trials would seem to merit much more attention than they have in the past. They can provide vital feedback to the biologist, needed information for the economist (though the results may need further deflation), and serve as an educational device for farmers. Still, they may not be appropriate in every case. Before much more can be said about them, they need to be the subject of further analysis.

Conclusion

Improvement in the methodology for the evaluation of research on crops needs to be matched by improvements in the measurement of the basic yield data. The initiation or expansion of farm-level trials offers one promising way to obtain more robust data at an earlier date. But they are likely to remain only in the promising category until more is known about them--the extent to which they are actually utilized, and their more precise advantages and limitations.

Economists should be involved in such an appraisal, just as they should be involved in the conduct and analysis of trials results. Despite the potential importance of such an activity, many economists may not find actual involvement in trials an attractive prospect. It would involve fairly long-term field work and the results are not likely to lead to spectacular results. Time spent on such activities is time away from other activities where the economist might feel more at home or which might be thought to lead to fame or fortune.

But until such steps are taken, we simply may not have a very sturdy empirical base for evaluating the potential yield effect of a new technology at the farm level. There is, moreover, an increasing need to know more about the effect of improved technology at an earlier stage of the game than has hitherto been possible. This necessitates earlier and fuller involvement of economists in the measurement of yields.

Footnotes

1/See, for example, R.K. Lindner and F.G. Jarret. "Supply Shifts and the Size of Research Benefits." American Journal of Agricultural Economics, February 1978 (Vol. 60, No. 1), pp. 48-58.

2/Dana G. Dalrymple. Development and Spread of High-Yielding Varieties of Wheat and Rice in the

3/These are often known as nurseries. A number of uniform nurseries are, for example, conducted for the major market types of wheat in the United States as a cooperative USDA-state venture. See, for example, P.S. Baenziger and J.G. Moseman, "Results from the Cooperative 1978 Uniform Southern Soft Red Winter Wheat Nursery," USDA/SEA/NE Region in Cooperation with State Agricultural Experiment Stations, Beltsville, Md., PGGI-78/9, October 1978, 39 pp.

4/See, for example: K.D. Wilhelmi, et. al., Results of the Eighth International Winter Wheat Performance Nursery Grown in 1976, University of Nebraska Agricultural Experiment Station (in cooperation with USDA/SEA and USAID), Research Bulletin 285, July 1978, 232 pp.; and Report of the Third Conference, May 30-June 2, 1979, International Rice Testing Program for Latin America, CIAT (with IRRI), Series 03ER-3 (February 1980), 62 pp.

5/Baenziger and Moseman, op. cit., p. 1.

6/As part of a recent study, I tried to summarize the reported yield advantage for semidwarf wheat varieties as reported in the variety announcements in Crop Science. This process produced many figures, but they were not highly standardized and were not easily compared or summarized. In some cases, only a nonquantitative general statement was given, such as "greater than" or "superior to." And as might be expected, the figures represented widely different periods and growing conditions Dana G. Dalrymple Development and Spread of Semidwarf Varieties of Wheat and Rice in the United States: An International Perspective, USDA/OICD (in cooperation with USAID) Agricultural Economic Report No. 455, June 1980, p. 103.

7/For a recent example, see L.G. Campbell and H. N. Lafever, "Effects of Locations and Years Upon Relative Yields in the Soft Red Winter Wheat Region," Crop Science, Jan.-Feb. 1980 (Vol. 20, No. 1), pp. 23-28.

8/In one Australian study where many of the production factors were standardized, the differences were thought to be largely due to greater labor availability and hence improved timing of operations under the experimental conditions. Bruce Davidson, "Crop Yields in Experiments and on Farms," Nature May 5, 1962 (Vol. 194, No.4827), pp. 458-459; B.R. Davidson and B.R. Martin, "The Relationship Between Yields on Farms and in Experiments," Australian Journal of Agricultural Economics, December 1965 (Vol. 9, No. 2), pp. 129-134, 138-139.

Rice Yields in Asia, 1974-77, IRRI, 1979, 411 pp. Also see R.W. Herdt and Randolph Barker, Multi-Site Tests, Environments, and Breeding Strategies for New Rice Technology, IRRI, Research Paper Series No. 7, March 1977, 32 pp.

10/Zvi Griliches: "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica, October 1957 (Vol. 25, No. 4), pp. 516-517,; "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, October 1958 (Vol. 66, No. 5), p. 42.

11/Harry W. Ayer and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil, American Journal of Agricultural Economics, November 1972 (Vo. 54, No. 4), p. 558.

12/Gerald R. Saylor, "Social Rates ... Comment," American Journal of Agricultural Economics, February 1974 (Vol. 56, No. 1) p. 171.

13/Harry W. Ayer and G. Edward Schuh, "Social Rates ... Reply," American Journal of Agricultural Economics, February 1974 (Vol. 56, No. 2), p. 175.

14/Saylor, op. cit., pp. 171-174.

15/Ayer and Schuh, op. cit. (1974), pp. 175-176.

16/Alberto R. Musalem, "Social Rates ... Comment," American Journal of Agricultural Economics, November 1974 (Vol. 56, No. 4), p. 838.

17/The discussion also took up important questions concerning partial and general equilibrium effects, but these have not been noted here.

18/Reed Hertford, Jorge Ardilla, Andres Rocha, and Carlos Trujillo, "Productivity of Agricultural Research in Colombia," in T. M. Arndt, D. G. Dalrymple, and V.W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research, University of Minnesota Press, 1977, pp. 86-123.

19/Ibid, p. 89.

20/Ibid., pp. 99, 100, 108, 109.

21/Scobie, for instance, later tried to utilize the rice data for estimating the yield superiority of improved varieties at the national level but obtained some puzzling results and ultimately did not use them. Grant M. Scobie and Rafael Posada T., The Impact of High Yielding Rice Varieties in Latin America, with Special Emphasis on Colombia, International Center for

22/Dana G. Dalrymple, "Evaluating the Impact of International Research on Wheat and Rice Production in the Developing Nations," in Arndt, Dalrymple, and Ruttan, op. cit., pp. 189, 190, 197-200.

23/Dalrymple, op. cit. (1980).

24/Advice for farmers wishing to conduct their own trials has recently been provided by Howard N. Lafever and Larry G. Campbell, "How to Set Up, Evaluate Yield Trials on Your Own Farm," Crops and Soils, November 1976 (Vol. 29, No. 2), pp. 13-17; and Charles E. Sommers, "On-Farm Tests --How to Put One Together," Successful Farming, February 1980 (Vol. 78, No. 3), p. 25 (published in the January 1980 edition on some regions).

25/See: S.K. DeDatta, K.A. Gomez, R. W. Herdt, and R. Barker, A Handbook on the Methodology for an Integrated Experiment-Survey on Rice Yield Constraints, IRRI, 1978, 59 pp.; K.A. Gomez, "On -Farm Testing of Cropping Systems" in Symposium on Cropping Systems Research and Development for the Asian Rice Farmer, IRRI, 1977, pp. 227-239; and R. K. Perrin, D. L. Winkelmann, E.R. Moscardi, and J.R. Anderson, From Agronomic Data to Farmer Recommendations; An Economics Training Manual, CIMMYT, Information Bulletin 27, 1976, 51 pp. and Planning Technology Appropriate to Farms; Comments and Procedures, (YMMT, Economics Program, 1980 in Press).

26/This paragraph is principally drawn from John H. Sanders and John K. Lynam, "Economic Analysis of New Technology in the Bean and Cassava Farm Trials of CIAT," CIAT, March 1980, 25 pp. (to be submitted to Agricultural Systems) and a letter from Sanders dated June 23, 1980. I have also drawn from their paper "Defining the Relevant Constraints in Crop Programs: Data Requirements to Improve Research Resource Allocation," April 1980, 14 pp. (submitted to Agricultural Administration). It is hoped the authors will spell out their experiences with farm trials in greater detail in the future.

27/Historical perspective on farm demonstration work in the United States is provided in Alfred Charles True, A History of Agricultural Extension Work in the United States, 1785-1923, USDA, Misc. Pub. No. 15, October 1928, pp. 58-65. Some more recent comments, in a global context, are provided in Johnson E. Douglas (compiler and editor), Successful Seed Programs: A Planning and Management Guide, Westview Press, 1980, pp. 155-157.

28/Some related questions which might be considered are noted in Sanders and Lynam, op. cit. (April 1980). Two Australians, as mentioned in note 8, have attempted to delineate the relation-data requirements for such an approach might limit its usefulness, it might be instructive to try to repeat this study for a more recent period and also in a different setting. Davidson, *op. cit.*, and Davidson and Martin, *op. cit.*

EXPERIMENT STATION EXPENDITURES: STATE SHARE AND POPULATION EFFECTS

John A. Miranowski and Wallace E. Huffman*

There are a growing number of studies that estimate the economic returns to public sector agricultural research. The estimated rates of return from these studies should be an important input into public sector decisionmaking on the allocation of federal and state funds to agricultural research. However, there have been few attempts to develop and fit empirical models that explain resources allocated to agricultural experiment station research. Some work has been done by Peterson (1969), Guttman (1978), and by us in an earlier paper (Huffman and Miranowski).

In our earlier paper, we developed a model of resource allocation for state-produced research by agricultural experiment stations consisting of a demand and supply equation for research, an equation for allocating state government revenues to research, and an expenditure market "equilibrium" equation. A reduced-form expenditure equation was fitted to 144 state observations obtained by pooling cross-sectional data on the 48 states for 1960, 1965, and 1970. The fitted model was quite successful in explaining research expenditures per capita.

In this paper, we extend our earlier analysis. We consider the separate impact of federal (CSRS) funding, population size, and number of farms on agricultural experiment station expenditures. Also, we consider alternative specifications of the dependent variable of the reduced-form expenditure equation. They are total expenditures, and the total expenditures deflated by population, number of farms, and total agricultural output.

Original Model of Resource Allocation to State Experiment Stations

In an earlier paper (Huffman and Miranowski), we estimated a model of resource allocation for state-produced research at agricultural experiment stations consisting of demand and supply equations for applied research, an equation for allocating state revenues to research, and an expenditure "market" equilibrium equation. We assumed that demanders and suppliers of research interact through the state legislature to determine the "equilibrium" size of expenditures on experiment station research.

The quantity demanded of indigenously applied agricultural research was specified to be a function of the size and other characteristics of a state's agricultural output, agricultural input prices, farmers' education, extension, and agricultural research in other states. The characteristics of a state's agricultural output were primary determinants of shifts in the demand for indigenous applied agricultural research. The diversity of agricultural products increased the demand for indigenous applied research, implying the final research products are commodity specific.

Indigenous applied agricultural research was produced and supplied by agricultural experiment stations. The production of research requires, as inputs, the services of administrators, researchers (or scientists), research assistants, and secretaries, as well as scientific publications, office space and equipment, laboratory space and equipment, electronic computers, greenhouse space, experimental plots and farms, and research animals and plants. As a first approximation, we assumed agricultural experiment stations produce research output at minimum cost; directors choose input combinations that minimize the cost of producing a given quantity of research, and they do not change cost-minimizing input combinations because particular inputs yield satisfaction directly to them.

The supply or cost function of indigenously applied agricultural research was specified to be a function of prices of variable inputs, of the quantity of research output, and of factors exogenous to current resource allocation decisions. The last set of variables was chosen to measure the efficiency of research production

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of research appointments, the extent of Ph.D. programs, extension contact with researchers, availability of borrowable research, number of final research areas, and the number of research centers.

Demanders of research did not pay suppliers of research in our model, but rather, decisions were made at the state government level on the share of state revenue to be spent on indigenously applied agricultural research. Although the demand and supply functions for research provided an equilibrium "shadow" price and quantity, the model required a behavioral equation for allocating state government revenue (McMahon) to agricultural research (or to nonresearch activities). We took the size of total state governmental revenues (which includes intergovernmental transfers) as predetermined, but we took the share of these revenues allocated to agricultural research as endogenous. Thus, political-economic clout was required to obtain funds for agricultural research. The director of the agricultural experiment station would request research funds based upon his information of research costs and of the demand for research conveyed to him through contact with producer groups, advisory boards, input supply firms, and feedback through extension personnel. Demanders may lobby the state legislator directly or through interest groups to achieve their political influence.

We hypothesized that farm owner-operators, operators of large farms, and farm organizations were the strongest lobbyists for agricultural research. State agricultural research expenditures were positively related to the share of owner-operator and large farms. As a measure of farm organization lobbying, we used multiple membership in farm cooperatives, which was also positively related to research expenditures.

The final equation of the model was the expenditure "market" equilibrium condition; desired agricultural research expenditures must equal state revenue allocated to agricultural research. We assumed that each of the four equations (including an eqilibrium condition) had a $\log_e$ linear form, and we derived a reduced-form expenditure equation and reduced-form coefficients from the three-equation system.

Extension and Respecification of the Model

We propose to extend and respecify the original model of resource allocation for research at state agricultural experiment stations. The model will be extended to include the impacts of federal funding, size of state population, and number of farms. Also, alternative specifications of the dependent variable will be considered, including total research expenditures population.

Historically, federal funds appropriated on a formula basis (CSRS funds) have been a primary source of state agricultural experiment station funding. Although state appropriations for research have substantially exceeded federal support in most states in recent years, the federal contribution can be expected to have a significant income effect on total station research expenditures. *A priori*, the direction of the income effect of federal funds on research expenditures is uncertain. We might expect the marginal effect of CSRS funds on total research expenditures to be positive. If federal funds replace state funds, the marginal effect on total research funds of a $1 increase in federal money would be less than $1.

The size of the state's population is a scale variable. Increasing a state's population, holding all other variables expressed in per-capita units constant, will increase the number of both direct and indirect beneficiaries of agricultural research expenditures, as well as the revenue base for state appropriations.

In this paper, we hypothesize that the number of farms enters both the research demand, supply, and allocation equations. Holding agricultural output constant, the general public might prefer that a larger, as opposed to smaller, number of farms should benefit from research. This would parallel Orr's argument for the public-good nature of AFDC income transfers. On the supply side, the marginal cost of distribution of research output to additional farms is positive, but is small relative to the marginal cost of knowledge production. The net effect of number of farms on research expenditures is uncertain.

Station research expenditures were deflated by population in the original model. Cuttman (1978) used per-capita units in his empirical analysis. The per-capita specification also has the advantage of a more homoscedastic error term than a total expenditures specification. Others (*e.g.*, Orr) have used number of recipients as the deflator. In addition to per-capita units, we consider three alternative specifications of the dependent variable: (1) total expenditures, (2) expenditures per unit of agricultural output, and (3) expenditures per farm. When using per-farm units, the appropriate exogenous variables are also deflated by the number of farms. Intuitively, a particular specification of the model may seem more appropriate, but the algebraic differences are not overly significant, and the empirical results should be similar.

the variables, and the regression results from fitting the reduced-form of the state expenditure equation for experiment station research are presented and discussed in this section.

The Data Base and the Variables

The basic data source on expenditures and other characteristics of the agricultural experiment stations is the USDA publication, Funds for Research of State Agricultural Experiment Stations and Other State Institutions. States in the conterminous United States are the units of observation, and expenditures for the fiscal years of 1960, 1965, and 1970 are used as the dependent variable. The cross sections are combined to provide a more rigorous test of the model.

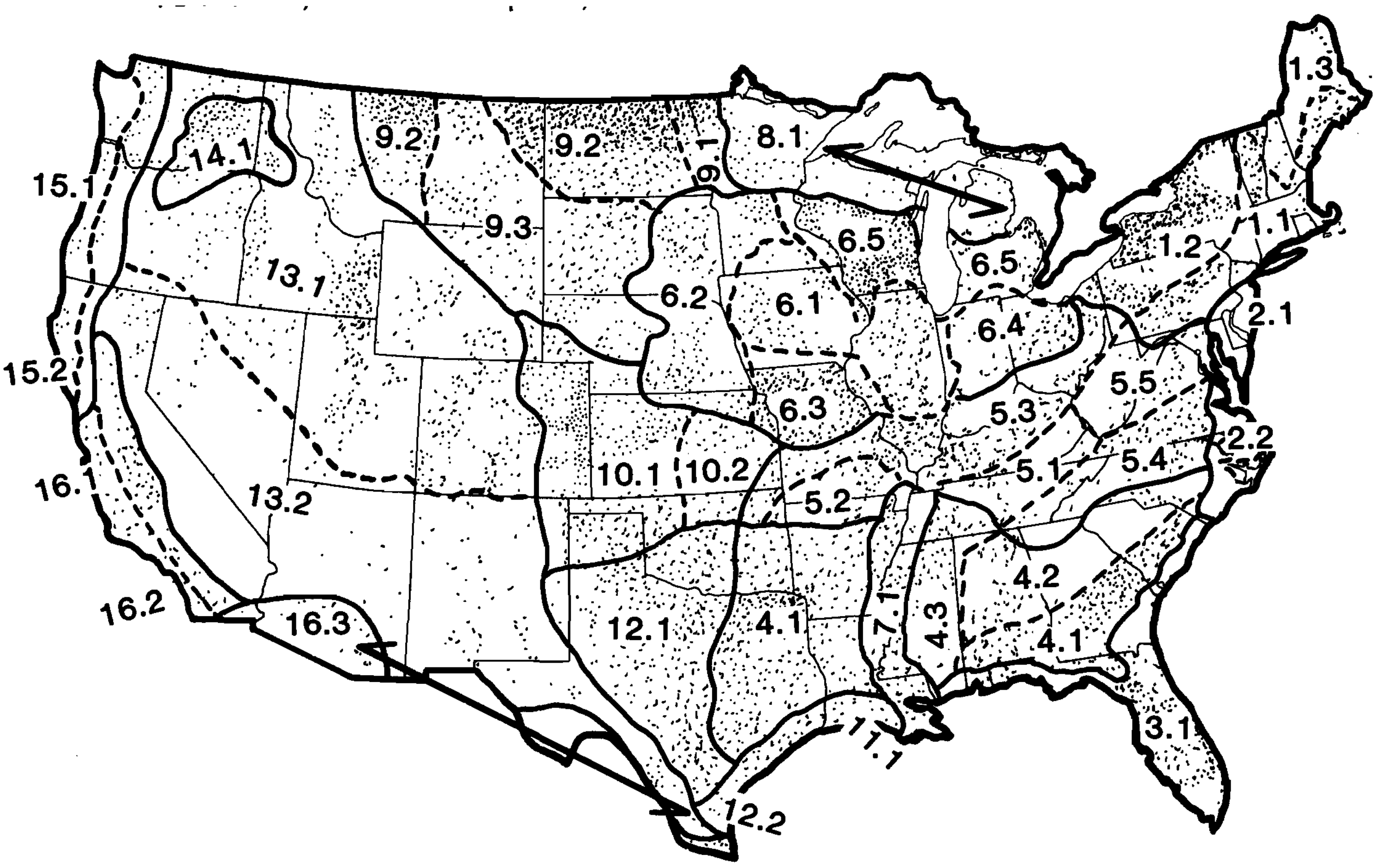
Most of the variables are constructed on a state per-capita or per-farm basis by dividing them by the size of the state's population (U.S. Dept. of Commerce, 1961, 1966, and 1971) or by the state's number of farms (U.S. Dept. of Commerce, 1962, 1968, and 1973), respectively. Our original model used state population as the deflator of the appropriate variables. This analysis compares the original specification of the dependent variable with agricultural research expenditures deflated by number of farms, by agricultural output, and undeflated. The alternative deflators do have implications for the public/private-good nature of agricultural research knowledge.

The dependent variable is a state's grand total obligation of funds for the fiscal year by the experiment station (and other state institutions) less nonfederal funds available from fees, sales and miscellaneous sources, then divided by the size of its population or by its number of farms. Agricultural output is measured as net annual sales (total value of farm products sold, less purchases of livestock and poultry and of noncommercial feeds for livestock and poultry), (U.S. Dept. of Commerce, 1962, 1968, and 1973) per capita or per farm, lagged one year. An index of concentration (diversity) of a state's agricultural output is constructed as the summation of the squared production share of each of 18 different agricultural commodities or commodity groups. The index is largest if a state's agricultural output consists of only one commodity or commodity group (it is one), and is smallest if a state produces an equal value of each of 18 different commodity groups (18/324). For input prices, we use only a state's annual average hourly wage rate for hired labor, without board and room, lagged one year (USDA, 1961, 1965, and 1970). The education level of farm operators is a Welch-weighted

tension is the grand total of a state's expenditures on extension per capita or per farm, lagged one year.

We constructed two measures of research activity outside a given state from data made available to us by Robert Evenson and described in Evenson (1978). The relevant set of states to consider in constructing these variables was determined by the boundaries of geoclimatic regions and subregions derived from the 1957 Yearbook of Agriculture (see Figure 1). These areas have relative homogeneity of soils and climatic factors. The subregional applied research stock (competitive research) is the summation of past commodity-specific livestock and crop research expenditures, and applied agricultural engineering and farm management research expenditures aggregated over states with similar agricultural subregions outside the state. Applied research expenditures were assumed to have a 30-year useful life, and linear weights were applied to aggregates over time with seven years of increasing, eight years of constant, and 15 years of declining weights (Evenson, 1978). Basic research is applicable over a wider geoclimatic area. The regional basic research stock (borrowable research) is the summation of past basic research expenditures for states in similar geoclimatic regions outside the state. Basic research was assumed to have a 40-year useful life, and linear weights were applied to aggregates over time with seven years of increasing, eight years of constant, and 25 years of declining weights. Outside applied and basic research are in per-capita or per-farm units.

Four characteristics associated with agricultural experiment stations follow. A research center's variable is derived as the number of research stations and substations (USDA, Professional Workers in State Agricultural Experiment Stations), including main campus, per 10,000 farms. The average share of budgeted time for research is the number of full-time equivalent station researchers, divided by the total number of station researchers engaged full- or part-time in research (USDA, Funds for Research). A variable measuring the size of the university's Ph.D. degree programs is derived. This variable is defined as the annual average (two-years) number of Ph.D. degrees earned in other areas (excluding agriculture and forestry) at universities associated with agricultural experiment stations (U.S. Dept. HEW, Earned Degrees Conferred) relative to the size of the state's population. The Ph.D. degree variable measures the potential for intrauniversity borrowing of knowledge by station researchers.



1. Northeast Dairy Region
2. Middle Atlantic Coastal Plain
3. Florida and Coastal Flatwoods
4. Southern Uplands
5. East-Central Uplands
6. Midland Feed Region
7. Mississippi Delta
8. Northern Lake States
9. Northern Great Plains
10. Winter Wheat and Grazing Region
11. Coastal Prairies
12. Southern Plains
13. Grazing -- Irrigated Region
14. Pacific Northwest Wheat Region
15. North Pacific Valleys
16. Dry Western Mild-Winter Region

(U.S. Dept. Comm., Statistical Abstracts). The impact of federal funding on a state's agricultural experiment station research expenditures (i.e., the substitutability between state and federal appropriations for SAES research) is measured by CSRS funds (USDA, Funds for Research) per capita or per farm. Farm size distribution is measured as the share of large farms (sales ≥ $40,000) and the share of medium-sized farms (sales $2,500-39,999). The proportion of owner-operators is a weighted average number of full owners and of part owners. Full owners are given an arbitrary weight of 1, and part owners a weight of 0.5. The only accessible farm organization membership data are for cooperatives. The cooperative membership variable is the total estimated number of memberships in marketing, farm supply, and related service cooperatives. Average share of budgeted time for research is the number of full-time equivalent station researchers, divided by the total number of station researchers engaged full- or part-time in research (USDA, Funds for Research). Two variables measuring Ph.D.-to-research faculty ratio is the (three-year centered) average number of Ph.D. degrees earned in agriculture and forestry from departments associated with the agricultural experiment station (U.S. Dept. HEW, Earned Degrees Conferred), divided by the number of full-time equivalent station researchers. The Ph.D. degrees in other areas is the annual average (two-years) number of Ph.D. degrees earned in other areas (excluding agriculture and forestry) at universities associated with agricultural experiment stations (U.S. Dept. HEW, Earned Degrees Conferred) relative to the size of the state's population.

The state budget constraint is total revenue per capita of the state government from all sources, including intergovernmental transfers (U.S. Dept. Comm., Statistical Abstracts). The impact of federal funding on a state's agricultural experiment station research expenditures (i.e., the substitutability between state and federal appropriations for SAES research) is measured by CSRS funds (USDA, Funds for Research) per capita or per farm. Farm size distribution is measured as the share of large farms (sales ≥ $40,000) and the share of medium-sized farms (sales $2,500-39,999). The proportion of owner-operators is a weighted average number of full owners and of part owners. Full owners are given an arbitrary weight of 1, and part owners a weight of 0.5. The only accessible farm organization membership data are for cooperatives. The cooperative membership variable is the total estimated number of memberships in marketing, farm supply, and related service cooperatives (USDA, Statistics of Farmer Cooperatives) per capita or per farm.

The results from fitting reduced-form expenditure equations by the method of least-squares to the 144 pooled observations are reported in Tables 2 and 3. These results include the alternative specifications of the dependent variables, as well as the model extensions including state population, number of farms, and federal funding. The hypothesized positive relationship between the size of agricultural output and expenditures on agricultural research is consistent. The negative coefficient, when expenditures are deflated by output, is not inconsistent. Algebraically, the coefficient of ln(AGOUT) in the ln(RY) equation should be equal to the coefficient, minus one of ln(AGOUT) in the ln(R) equation. All four specifications support the hypothesis of commodity specificity of research final products although the CONC coefficient is not statistically significant in the total expenditure model. The interaction terms are reasonably consistent across models.

The signs on LAR and MED are not consistent with the hypothesized relationship in the total expenditure, extended per-capita and per-farm models, but these coefficients are not significantly different from zero. The same result is obtained for the share of owner operators in the total expenditure specification.

The ln(WAG) and ln(ED) coefficients are consistent across models and significantly different from zero at the 5% level. Increasing farm wage rates induce research expenditures to develop labor-augmenting technologies. Also, the sign of the education coefficient in the original model, which was puzzling, consistently has a negative impact on the demand for station research.

The research borrowing variables continue to perform well in the alternative specifications. The negative relationship between ln(ARES) and total expenditures is puzzling but statistically insignificant. Conceivably, states with large total expenditures on station research (e.g., California, New York, Florida) are sufficiently isolated from similar geoclimatic regions where competitive applied research may occur.

The allocation equation variables, ln(REV) and ln(COOP), produce results consistent with those of the original model. Likewise, the coefficients of the variables for supply characteristics of station research are consistent.

The variables of particular interest in this analysis are ln(FED), ln(POP) and ln(FARM), which extend the original model. The impact of CSRS funds per capita on total state research expenditure per capita is negative, if we hold constant the population and number of farms. Otherwise, the impact on total research expenditures of ln(FED)

Variables	Symbol	Unit	Mean	Standard Deviation
Expenditures on Experiment Station Research Per Capita	R	$0.1 per person	14.0	9.3
Net Agricultural Output Per Capita	AGOUT	$s of output per 1,000 people	2,359.0	2,174.3
Index of Commodity Concentration of Agricultural Output	CONC	--	0.21	0.08
Proportion Large Farms	LAR	--	0.07	0.06
Proportion Medium-Sized Farms	MED	--	0.53	0.15
Proportion Owner-Operators	OWN	--	0.73	0.09
Wage Rate of Hired Farm Labor	WAGE	$ per hour	1.20	0.31
Index of Farmers Education	ED		1.49	0.28
Extension Expenditures Per Capita	EXT	$ per person	1.39	0.81
Research Centers Per Farm	CEN	Centers per 10,000 farms	3.06	4.06
Subregional Applied Research Stock Per Capita	ARES		16.12	19.80
Regional Basic Research Stock Per Capita	BRES		3.92	5.47
Budgeted Share of Research Time	SR	--	0.70	0.12
Ph.D. Degrees Earned in Agriculture and Forestry Per Full-Time Equivalent Researcher	APHD	Ph.D. degrees per researcher	0.07	0.08
Ph.D. Degrees Earned Outside Agriculture and Forestry Per Capita	OPHD	Ph.D. degrees per 1,000 people	0.03	0.03
State Revenue Per Capita	REV	$1,000 per capita	0.984	1.02
Co-op Membership Per Capita	COOP	Member/1,000 people	57.42	73.14
Total Expenditures on Exp. Station Research	TR	$100	38,289.8	34,922.2
Exp. on Experiment Station Research Per Unit Net Agricultural Output	Ry	$ per $ output	.0089	.0076
Expenditures on Exp. Station Research Per Farm	RF	$100 per farm	1.28	1.77
Federal (CSRS) Exp. on State Experiment Station Research Per Capita	FED	$0.1 per person	4.28	3.10

Variables	Symbol	Unit	Mean	Standard Deviation
Number of Farms	FARM	Number	66,524.3	53,740.4
State Population	POP	1000's persons	3,983.4	4,107.1
Net Agri. Output Per Farm	AGOUTF	$100 output per farm	128.49	109.24
Extension Exp. Per Farm	EXTF	$1000 per farm	.09	.08
Subregional Applied Research Stock Per Farm	ARESF		2.14	6.82
Ph.D. Degrees Earned Outside Agriculture and Forestry Per Farm	OPHDF	Ph.D. degrees per farm	.004	.006
Co-op Membership Per Farm	COOPF	Members/farm	2.29	1.85
Federal (CSRS) Expenditures on State Experiment Station Research Per Farm	FEDF	$100 per farm	.39	.72

Table 2. OLS Estimates of Reduced-Form Models for Expenditures on State Agricultural Station Research Deflated by Output, Farms, and Population, 1960, 1965, and 1970.

Variable	(1) ln(RY)	(2) ln(RY)	(3) ln(TR)	(4) ln(TR)	(5) ln(R)	(6) ln(R)
Constant	-1.30 (-1.99)[a]	2.46 (2.12)	8.13 (11.86)	2.40 (2.06)	-1.12 (-1.72)	2.40 (2.06)
ln(AGOUT)	-.67 (-7.81)	-.46 (-3.76)	.53 (5.91)	.51 (4.15)	.31 (3.64)	.51 (4.15)
CONC	3.47 (1.64)	5.40 (2.67)	6.78 (3.06)	5.47 (2.68)	5.47 (1.74)	3.67 (2.68)
LAR	2.06 (2.29)	-.26 (-.22)	-.86 (-.92)	-.07 (-.06)	2.08 (2.33)	-.07 (-.06)
MED	.53 (1.93)	.03 (.11)	-.30 (-1.07)	-.03 (-.09)	.43 (1.60)	-.03 (-.09)
OWN	.86 (2.61)	.39 (1.19)	-.02 (-.06)	.28 (.86)	.72 (2.26)	.28 (.86)
ln(WAG)	.55 (2.11)	.70 (2.86)	.92 (3.35)	.68 (2.76)	.54 (2.07)	.68 (2.76)
ln(ED)	-.54 (-2.34)	-.79 (-3.56)	-1.08 (-4.49)	-.71 (-3.15)	-.47 (-2.05)	-.71 (-3.15)
ln(EXT)	.33 (3.26)	.35 (3.65)	.33 (3.12)	.37 (3.78)	.35 (3.45)	.37 (3.78)
ln(CEN)	.22 (5.61)	.13 (2.95)	.05 (3.12)	.11 (2.47)	.20 (4.95)	.11 (2.47)

Variable	(1) ln(RY)	(2) ln(RY)	(3) ln(TR)	(4) ln(TR)	(5) ln(R)	(6) ln(R)
ln(ARES)	.11 (3.32)	.04 (1.16)	-.02 (-.51)	.03 (.98)	.10 (3.01)	.03 (.98)
ln(BRES)	-.02 (-1.90)	-.04 (-3.20)	-.06 (-4.62)	-.04 (-3.16)	-.03 (-1.96)	-.04 (-3.16)
ln(SR)	.38 (3.08)	.39 (3.33)	.44 (3.39)	.40 (3.40)	.39 (3.18)	.40 (3.40)
ln(OPHD)	.05 (2.74)	.05 (2.98)	.05 (2.61)	.05 (3.05)	.05 (2.84)	.05 (3.05)
ln(REV)	.07 (1.03)	.08 (1.24)	.14 (1.83)	.15 (2.22)	.14 (1.98)	.15 (2.22)
ln(COOP)	.06 (1.93)	.07 (2.41)	.07 (2.15)	.07 (2.40)	.06 (1.97)	.07 (2.40)
(CONC) x ln(AGOUT)	-.51 (-1.93)	-.79 (-3.07)	-.97 (-3.49)	-.79 (-3.07)	-.53 (-2.02)	-.79 (-3.07)
(LAR) x ln(ARES)	-.67 (-2.51)	-.34 (-1.34)	-.05 (-.18)	-.33 (-1.28)	-.63 (-2.39)	-.33 (-1.28)
ln(FED)	.15 (1.79)	-.32 (-2.12)	-1.02 (-11.50)	-.27 (-1.75)	.18 (2.08)	-.27 (-1.75)
D70[b]	.37 (2.20)	.56 (3.46)	.86 (4.82)	.67 (4.11)	.50 (2.94)	.67 (4.11)
D60	.13 (.70)	-.06 (-.35)	-.29 (-1.55)	.11 (.60)	.29 (1.63)	.11 (.60)
ln(FARM)		-.14 (-1.26)		-.13 (-1.15)		-.13 (-1.15)
ln(POP)		-.29 (-1.75)		.73 (4.38)		-.27 (-1.64)
R^2	.92	.93	-.94	.95	.92	.93

[a] Values in parenthesis are t-statistics.

[b] D70 and D60 are dummy variables for 1970 and 1960, respectively.

Farms, 1960, 1965, and 1970.

Variable	(1) ln(RF)	(2) ln(RF)
Constant	-1.83 (-2.89)	2.82 (2.60)
ln(AGOUTF)	.72 (5.54)	.66 (5.57)
CONC	2.64 (1.98)	3.51 (2.92)
LAR	-1.82 (-1.89)	-1.56 (-1.78)
MED	-.06 (-.21)	-.14 (-.51)
OWN	.64 (1.87)	.33 (1.05)
ln(WAG)	.61 (2.39)	.77 (3.31)
ln(ED)	-.55 (2.42)	-.87 (-4.00)
ln(EXTF)	.41 (4.22)	.27 (2.86)
ln(CEN)	.11 (2.46)	.10 (2.43)
ln(BRES)	-.04 (-3.89)	-.04 (-4.21)
ln(SR)	.29 (2.36)	.37 (3.24)
ln(OPHD)	.05 (2.82)	.05 (2.99)
ln(REV)	.03 (.51)	.10 (1.50)
ln(COOPF)	.05 (1.46)	.04 (1.46)
(CONC) x ln(AGOUTF)	-.74 (-2.82)	-.89 (-3.74)
D70	.26 (1.57)	.50 (3.22)
D60	.17 (.92)	-.04 (-.21)
ln(FEDF)	.41 (5.40)	-.26 (-1.79)
ln(POP)		.24 (4.76)
ln(FARM)		-.70 (-5.74)
R2	.96	.97

total state research expenditures. Likewise, the current concern over real reductions in Hatch funding may result in an increase in total experiment station research expenditures, other things equal. To say the least, the implications are somewhat surprising, especially since we are holding other factors fixed, and since these results are consistent across equations.

States with more farms tend to spend less per capita and per unit of agricultural output on experiment station research, but the coefficient on ln(FARM) is not significantly different from zero at a standard level of confidence. The number of farms, which means more potential recipients of research knowledge (i.e., public good), has a negative impact, even when holding the size distribution of farms constant. Economies may exist in supplying public research knowledge to a larger number of recipients, other things equal, producing the negative coefficient on ln(FARM). Population does have a positive impact on the total research expenditures per capita and per farm equations. Larger states spend more total dollars on agricultural research, more per farm, and more per capita.

The statistical significance of some (e.g., LAR, MED, OWN, ln(REV)) of the original explanatory variables is reduced by the inclusion of ln(FED), ln(POP), and ln(FARM) in the model, but generally, the signs are consistent.

In the per-farm equation, increasing the share of large farms reduces per-farm expenditures on agricultural research. It may indicate that larger farmers acquire privately supplied research knowledge, or that public support for research per farm is less as the share of large farms rises.

Implications and Summary

All of our model specifications are really very similar, so one should not be surprised by the similarity and consistency of the results. In most cases, the explanatory variables perform quite well. However, some specifications of the model (i.e., deflators) may have a stronger intuitive acceptance than others. An analysis of the residuals of the different specifications might provide some guidance in choosing between them.

Increasing (decreasing) CSRS funds for state experiment station research, holding population and number of farms constant, not only substitutes for other funds, but results in a decrease (increase) in total research expenditure. Although the result is surprising, among other things, it may indicate that formula funds, level of research output.1/

States with larger populations spend more on station research than their smaller counterparts; the relationship between ln(TR) and ln(POP) is positive. Yet, the negative relationship between population and per-capita research expenditures, holding other per-capita variables and number of farms constant, tends to support the hypothesis that agricultural research is a public good, whose consumption is nonrival (i.e., there are economies of size in the provision of public research knowledge, other things equal).

In supplying research knowledge to farmers, additional support for the public-good hypothesis is provided by the coefficient of ln(AGOUT) which is positive, but less than unity. Increasing agricultural output by 10% increases research expenditures, but only by 3 to 6%, indicates economies in spreading research output over more units of output.

The number of farms has a negative impact on research expenditures when holding population and agricultural output constant. Even though more farms imply more potential recipients of benefits of applied research and possibly greater numbers to influence state appropriations, the negative coefficient may reflect a less efficient farm sector. Also, larger numbers may create organizational problems that hamper effective lobbying efforts.

ACCOUNTABILITY IN RESEARCH THROUGH INDUSTRY FUNDING

Robert Lindner*

The large volume of research reported at this symposium is just one indication of the considerable cost involved in meeting the current public demand for evaluation of agricultural research. Presumably the principal reason underlying this demand is the fact that a high proportion of agricultural research is publicly funded, and unlike many other forms of investment, not necessarily subject to the discipline of market forces. This paper discusses a method of funding rural research in Australia 1/ which, at least in part, overcomes the inability to appropriate the benefits from research, and thus allows the industry to determine the level of funding and to control the allocation of research resources. The essential feature of what is known in the United States as the "check-off" system is a collective decision by an industry to impose a levy on its output to raise funds for research into industry problems.

In his address to the symposium, Ray Miller challenged agricultural economists to undertake more studies of the effectiveness of research management procedures in different countries. The difficulty, of course, with such cross-country institutional studies is that it is all too easy to describe differences, but all too difficult to determine whether, and how such differences affect performance. This paper is similarly long on description and short on analysis, but hopefully the discussion below of how industry funding of rural research operates in Australia may be of interest to the countries like the United States where its use is much less prevalent.

In Australia, the industry bodies which administer and allocate the research funds derived from a levy on production are known collectively as Rural Industry Research Funds, or RIRFs. To understand the role played by the RIRFs, it is necessary to know a little about how rural research _in toto_ is organized and funded. Table 1 provides an overview of the system for the financial year 1973-74, which unfortunately is the last year for which comprehensive data are available. However, with the exception of inflation, there have been no changes since then which would radically alter the situation depicted in Table 1.

It can be seen that, in contrast to the U.S.A., government research organizations carry out the greater part of all rural research conducted in Australia, with the commonwealth government (mainly CSIRO) accounting for 48%, and the state governments (mainly state departments of agriculture) accounting for an additional 39%. Higher education, which in some senses is also government, accounts for an extra 6%, leaving only 7% to be carried out by other bodies, including business enterprises.

Table 1 also reveals that direct government financing, typically by way of Treasury subvertion, is the dominant source of funds for the three most important groups of research organizations. The remainder mainly came from a combination of RIRFs (about 12% in the case of CSIRO, and about 9% for the state departments of agriculture) and from other government financed (but not industry controlled) research funds.

While there are important differences between individual RIRFs, all are organized in essentially the same manner, and the most important features include:

1) Agreement by members of the industry to impose a levy on output to provide funds for research into industry problems. For the 10 statutory RIRFs, which cover all the major industries, the levy is legally compulsory, but there are a similar number of non-statutory RIRFs covering some of the less important industries for whom the levy is voluntary.

2) Agreement by the commonwealth government to match the industry contribution, usually on a dollar-for-dollar basis. Hence, the amount of funds which RIRFs control, as opposed to collect from production levies, is approximately double the amount shown in Table 1.

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Research Organization	Commonwealth Government	State Government	Higher Education	Non-Profit Organizations	Business Enterprise	Total
Total Amount $(million)	67.3	55.0	8.2	2.4	7.3	140.2
Source of Funds (%)						
Commonwealth govt[a]	88	8	59	19	5	49
State govt	-	88	3	3	-	35
RIRF[b]	10	4	18	16	1	8
Other Sources	2	c	20	62	94	8
Total Sources	100	100	100	100	100	100

a Including matching grants to RIRFs.
b Excluding imputed value of commonwealth government matching grant.
c Less than 1%.

SOURCE: Industries Assistance Commission, "Financing Rural Research" 1976.

3) Allocation of funds to high-priority (for the industry) research projects. To ensure effective control over research priorities, industry representatives make up a majority of the membership of the management committees which make decisions about which research proposals to sponsor, but membership also includes several members from the scientific community plus at least one representative of government. Furthermore, most funds have a full-time executive and/or a system of advisory technical sub-committees to supplement the advice of the scientific members of the main allocating committee.

Advantages and Disadvantages of the RIRF System

The Industries Assistance Commission (IAC) enquiry into Financing Rural Research saw important advantages in this method of funding research, and strongly recommended that government support for the RIRF system be continued. The IAC was attracted by the idea of the customer/contractor principle proposed in the UK Rothschild Report as a means of ensuring accountability of the research system to social needs; but saw the RIRF system as a means of implementing this principle within a pluralistic funding system, and thereby avoiding the centralized bureaucratic system which was established in the United Kingdom. To quote, the IAC regarded the RIRFs as "an eminently suitable instrument for the assessment of priorities for each industry" (IAC, 1976, p. 47).

To appreciate why the IAC attached such importance to the role of the RIRFs given their relatively minor contribution to overall funding as revealed in Table 1, it is necessary to understand in some detail how the RIRFs operate. Out of a total of A$ 23 million allocated by the 10 statutory RIRFs in 1973-4, less than half was used to support most of the costs, including staff salaries, of entire research programmes, mainly in CSIRO, but also in the Bureau of Agricultural Economics. For this type of support, provided largely by the Wool RIRF, and to a lesser extent by the Meat RIRF, industry control over the direction of research is circumscribed by lack of flexibility in the current stock of human capital.

Most of the remainder of the RIRF funds are used to provide supplementary support for individual research projects, and are allocated on a competitive basis. Some RIRFs simply invite all research organizations to submit proposals for research relevant to the industry in question, and then sponsor those projects deemed to be of (potential) economic importance to the industry and of sufficient scientific merit. Other RIRFs decide on certain priority areas first, and then invite proposals for research on those areas. Where long-term work on a major industry problem is felt to be needed, they may virtually call for tenders to make specific contributions to the solution of the problem.

an influence on the direction of research equivalent to the proverbial tail which wagged the dog because they only fund direct experimental costs, including vital items of equipment in some cases. Other research costs, particularly salaries and infrastructural costs, which typically account for 70-80% of total research costs, are left to be paid for out of "core" funds provided to research organizations by direct government grants. Given the fixed nature of research personnel, this policy has allowed the RIRFs to exert an influence over the direction of rural research which far exceeds their contribution to research expenses.

Other advantages of the RIRF system noted by the IAC included the beneficial effect on efficiency of research agencies through being subject to external review, and the greater liaison and coordination of rural research brought about by contact between research workers and rural producers through representation on joint committees, and by sponsorship of conferences and workshops. The IAC also noted that the RIRF system of funding tends to share the costs of research between consumers and producers in the same proportion as the benefits of research, since the incidence of the production levy and of research benefits both depend on the elasticity of demand. This statement needs to be qualified in two respects, one being that only a proportion of research costs are funded by a production levy. The second qualification relates to the fact that a production levy will always shift the supply curve up in a parallel fashion, while the offsetting downward shift of the supply curve induced by implementation of (successful) research results need not be parallel. If the latter shift is divergent, the producers' share of research benefits will be less than the proportion of the production levy which they bear.

In theory, the almost intractable problem of determining the optimal level of investment in research could be solved by letting each industry decide for itself the rate at which to levy production to fund industry specific research. One difficulty with such an approach in practice is that research results are rarely entirely specific to a particular industry. Furthermore, these inter-industry spillover effects become more severe, the further a particular project is along the spectrum from applied to basic research. Another problem is that funds derived from production levies reflect current levels of production, whereas the optimal level of investment in research, given the considerable time lags involved, should be related to future levels of production. For instance, a RIRF system of funding would be most unlikely to carry out research leading to the development of a new industry.

viding funds by other means to support research. Nevertheless, the IAC enquiry felt that the RIRF system could exert an influence on research resource allocation between industries, and chose to regard the variation in the level of funding contributed by different industries as "a reflection of the consensus of opinion among primary producers as to the level of research support which is required by individual industries." Such a proposition is debatable given the fact that there are alternative sources of funds from industry specific research.

Table 2 provides information on rural research expenditures broken down by industries, and the contribution made by RIRFs to funding of industry specific research. It would be unwise to read too much into the figures in Table 2 as the IAC encountered a number of problems in collecting and classifying the data. Nevertheless, there is little evidence in the table to support the view that an industry can increase the relative share of research resources devoted to investigation of its problems if there are alternative sources of untied funds available to research organizations.

Apart from the more general drawbacks to industry funding of research due to inter-industry spillovers and other problems discussed above, the IAC noted several practical difficulties encountered by RIRFs operating in Australia. Some of these problems derive from the fact that for most RIRFs, levies are on a unit of output basis. As a result, the rate of growth of research funds from the levy has not kept pace with the rate of increase in research costs. Output levies also involve inequities where prices for a product vary substantially due to large quality differentials; while for industries facing a highly inelastic demand curve, levy collections vary inversely with ability to pay. For these reasons, the IAC enquiry strongly recommended that all RIRFs switch to a levy based on value of output. In recommending this change, it was recognized that it would tend to exacerbate another problem, namely the high administrative costs encountered by at least some industries in collecting the levy. To minimize this problem, the commission suggested collecting the levy as far down the marketing chain from the producer as feasible, and/or employing a standard value method of pricing commodities, such as beef, which are not homogeneous, and exhibit substantial price fluctuations over time and space as well as between different grades of output. Switching to a value-based levy also would tend to ameliorate the problem of fluctuations in levy income faced by the RIRFs. The IAC saw establishment of reserves by RIRFs as the best solution to this problem.

	GRP A$m. (X)	Av. Res. Expendit. A$m (Y)*	Research Intensity (100Y/X)	Est. % Prodn. Levy (Z)**	Est. % RIRF Share (2ZX/Y)
Wool	1044.1	9.74	.9	.53	114***
Sheepmeat	281.1	3.64	1.3	.16	27
Beef	936.1	11.01	1.2		
Dairy	463.2	6.98	1.5	.10	13
Pigs	136.0	1.37	1.0	.15	30
Poultry	104.3	1.17	1.1	.10	18
Eggs	125.4	.84	.7	.10	30
Other	9.0	14.12			
Total L/S	3099.2	48.86	1.6		
Wheat	710.4	4.93	.7	.07	20
Barley	135.2	.70	.5	NSR	
Oats	45.2	.35	.8		
Rice	29.1	.65	2.2		
Maize	9.4	.36	3.8		
Sorghum	63.5	.50	.8		
Cotton	29.8	1.25	4.2		
Tobacco	40.4	1.12	2.8	1.11	79
Sugar cane	218.8	2.61	1.2	NSR	
Other	731.1	7.34			
Total Crop	2012.9	19.80	1.0		
Dried Fruits	35.3	.37	1.1	.15	28
Grapes	36.2	1.59	4.4	NSR	
Citrus	44.5	1.05	2.4		
Stone Fruits	38.5	.98	2.5	NSR	
Pome Fruits	82.0	1.67	2.0	NSR	
Bananas	23.9	.43	1.8		
Potatoes	65.2	.83	1.3		
Tomatoes	35.1	.47	1.4		
Beans	7.9	.32	4.1		
Other	105.0	3.58			
Total Hort.	473.6	11.29	2.4		
Fisheries	101.2	5.51	5.4	.26	10
Forestry	168.7	7.42	4.4		

Source: Based on Industries Assistance Commission 'Financing Rural Research' 1976.

* The 'other' category for Average Research Expenditure includes research which could not be allocated to a specific industry as well as research on industries not listed in the table.

** Based on 1973-4 data only. Expresses levy funds, excluding commonweatlth government contribution, as a percentage of value of industry output. NSR indicates non-statutory RIRF relying on voluntary levy.

*** This anomalous figure probably is due to classification of some research funded by the Wool RIRF as sheep meat, or other industry research. The figure may also include some funds spend on wool promotion, frequently is less pressing for a value levy than a unit-output levy, but still might arise if research costs inflate at a faster rate than the increase in price of the commodity, and/or if future market prospects for the industry change in any way. Thus, it would seem desirable to make it as easy as possible to change the levy rate, and in particular, to avoid cumbersome procedures for doing so. A related problem facing government is the rate at which to subsidize, if at all, levy collections. The primary argument for such a subsidy is interindustry spillovers, but until such time as the relative importance of these has been established, the level of government subsidy will have to be determined arbitrarily.

To summarize, industry funding of research by way of production levy does partially overcome the appropriability problem, and provides a device for ensuing a degree of accountability on the part of rural research organizations to the needs of rural industries. However, society needs to provide alternative sources of funds as well, since the scope for funding research in this manner is limited to applied research and development work, and for even this type of work there is a case for governments to subsidize the RIRFs. Attention also needs to be paid to resolving several practical problems which otherwise might impair the efficient operation of the RIRFs.

Footnotes

1/This paper draws heavily on the following two publications:

Financing Rural Research, Industries Assistance Commission, Australian Government Publishing Service, Canberra, June 1976.

Jarrett, F. G. and R. K. Lindner. "Rural Research in Australia." In D. B. Williams (Ed.), Agriculture in the Australian Economy. Second edition. Sydney University Press (forthcoming, 1980).

ENTREPRENEURING SCIENTISTS INFLUENCE RESEARCH PROGRAM AS THEY SELECT RESEARCH TO PROPOSE

Janelle Ramsdale and Arnold Paulsen*

Agricultural experiment station scientists and administrators face the uncertain collective task of developing a research program that can be funded <u>and</u> will generate social value for society and themselves. Agricultural research findings impact all segments of society, but to different degrees and in different directions. Large farmers, small farmers, consumers, agribusiness, research-granting agencies, federal and state legislators, special interest groups, and fellow scientists all have research demands. Each client group would like more attention than it receives and even the U.S. Congress with the 1977 Act Title 14 expressed growing skepticism of the station's ability to equitably and efficiently allocate agricultural research resources.

Agricultural experiment station expenditures are largely politically appropriated and tax supported, and attract a large amount of public attention. Each year the number of budget examiners and the intensity of program reviews seem to grow. The experiment station has also been the subject of sharp criticism.1/

Uncertainties over the optimality of current programs and allocation of agricultural research funds also exist among experiment station directors and scientists. Harold Ottoson, in a presentation made to the scientists associated with NC-148, called attention to the hard choices--"administrators are faced with the need to examine the productivity of the investments which they make in various areas of research in the interests of: (a) better decisions in making resource allocations, (b) accountability to those who supply resources, and (c) in justifying the program to clientele and supporters" {6, p. 5}. Each year, science administrators say they must defend their experiment station programs by providing the public acceptable answers when they are asked such questions as: "Who do you serve?" and "To whom do you listen?"

A multi-leveled decisionmaking structure best describes program formation and the management of experiment station research resources. An accurate description and understanding of how research program decisions are made and how resource allocation could be influenced would help to meet internal and external criticisms, concerns, and questions. Paulsen and Kaldor {4} believe the decisionmaking structure consists of both external and internal decisionmakers. The major external decisionmaker is the U.S. Congress and the several state legislatures, who allocate funds between the agricultural research and other programs and agencies, decide the size of the station. The internal decisionmakers, the station directors, the department chairmen, and the scientists, decide which research activities to undertake and thereby determine the competitiveness of the station. Simply, "the internal decisionmakers decide the program and the external decisionmakers appraise the program and decide how much support to give it" {4, p. 10}.

The North Central Regional directors requested of NC-148 an explicit focus on the internal decisionmaking of the stations. Since each decisionmaker has a different role in the production of station research each of the three levels needs study. Station administrators and department heads define staff positions, hire scientists, request and supervise the construction of new facilities, and allocate the budget among departments. The scientists select research topics to propose and design research methods.

This beginning study focuses on the largest group of decisionmakers, the research scientists. Because scientists are the initiators of research proposals, they have the greatest short-run influence on the choice of topics. They also determine research resource productivity that is volume of information output through their work habits and research methods. The creativity and efficiency of the research process rests with the scientists.

The research scientist is the entrepreneur, the catalytic agent in the venturesome process of

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high-value topics. He assimilates demand and supply information pertaining to specific information usually far in the future. Entrepreneurial skills vary widely among scientists. Beginning scientists usually have a small enterprise involving only himself, minimal laboratory space, and one or two graduate students. Successful scientists manage a vast and complex, heirarchical organization using over millions of dollars per year. They have control over major capital investments in specialized facilities, equipment and information. They may employ several scientists, 20 or more graduate students and technicians. Entrepreneurship is very rare, productive and well rewarded.

Evenson writes, "In the research process, the researcher acts in some ways like the entrepreneur who is making a decision" {2, p. 166}. Every experiment station decisionmaker from founder to junior scientist, T.W. Schultz says, is an entrepreneur.

Even the words used to describe the entrepreneur in 1803 and translated from French seem to apply to experiment station scientists. Jean-Baptiste Say wrote that the entrepreneur is the economic agent who: "...unites all means of production--the labor of one (a graduate student?), the capital (a $50,000 grant?) or the land (laboratory?) of the others--and who finds in the value of the products which result (information) from their employment the reconstitution of the entire..." {1, p. 183}.

The research scientist faces numerous research possibilities and is constrained by scarce resources and the state of knowledge. Successful agricultural scientists exhibit leadership, creativity, accurate forecasts, and risk-bearing ability.

The entrepreneur in research leads a uniquely independent public organization or "research firm." Schultz explains, research requires the use of scarce resources (human skills and time, facilities) in the production of something of value (knowledge, new information), and qualifies and behaves as an "economic firm" in spite of its location in the public sector. Research is a production process. Business components such as inputs, outputs, techniques, storage, and sales can be specified. The objective is not profit maximization but utility maximization. This distinction creates no theoretical difficulties but severe empirical difficulties.

A representative one-third sample of 64 Iowa State scientists with some time budgeted in the experiment station was selected. The population was stratified by department, academic rank, and

proposed research was explained to administrators and adjusted to their interests.

The questionnaire about scientist research choice was completed during a one-hour personal interview with each scientist in 1979. We asked open-ended questions and took a flexible approach to perceive better the unique personality and operating style of each entrepreneur. Before interviewing scientists in any department, a meeting was held with the department head to explain the content and purpose of the interview and gather job description, internal subdepartment organization, delegation of decisionmaking and so on.

Each scientist's research decisionmaking process was described in three stages. The breadth with which a scientist defines his area of professional competence and the shape of the job description under which he is hired determine and limit in Stage I the research possibilities a scientist will consider when making research choices. It seemed often that the busier a scientist was and the more adequate his funding, the narrower he defined his area of professional competence, thereby eliminating consideration of many research possibilities.

The post-classification of area of specialization followed the "Manual of Classification of Agricultural and Forestry Research." The sample was almost evenly divided between medium and narrow specialization. Also medium and minor-time scientists were significantly more likely to describe their speciality in broad terms, while over half of the major-time scientists provided a very specific topical description of their professional specialization.

In Stage II, the research scientist was expected to assess his narrowed set of research possibilities with the help of messages or signals received from users of his information. A list of 14 major demanders of experiment station research was presented to each scientist. Each was to identify the sources from which he could recall receiving demand signals. Among those sending him signals, he was then asked to give a relative weight or actual influence each exerted on his research selections. The sources of signals with the greatest overall frequency were departmental colleagues, friends who are non-ISU scientists, and fellow professionals through journals and conventions.

Stratum	Broad Field of Science Only	Moderate Subdiscipline Also	Specific Subdiscipline plus Commodity
Department			
Animal sciences	0	43.8	56.2
Plant sciences	0	58.8	41.2
Social sciences	0	46.2	53.8
Academic Rank			
Full professor	0	51.4	48.6
Associate professor	0	58.3	41.7
Assistant professor	0	50.0	50.0
Research Time[a]			
Major time	0	37.9	62.1
Medium time	0	65.0	35.0
Minor time	0	64.3	35.7
Sample Total	0	52.4	47.6

[a] Significant chi-square at 90% confidence level.

Table 2. Percent of All Scientists Who Reported Receiving Demand From Each Source

Source	Percent
Departmental colleauges	79
Friends who are non-ISU scientists	71
Professionals through journals or conventions	65
DEO	65
ISU professors outside the scientist's department	59
Adopters of research results	59
Extension	50
Granting agencies	47
ISU Experiment Station administration	41
Regional research committees	41
General public, legislators	35
Private industry contract offers	29
Government contract offers	26
Mass media	15

Scientists were asked further to assign a relative amount of influence on his choices to each source. Many researchers received demand signals from a wide variety of sources, but ascribed important influence to only a few. No demand source exerted a uniform major influence on research selection. The most influential source was professionals through journals or conventions followed by departmental colleagues, non-ISU friends, and granting agencies. Major-time scientists gave high weights of influence to professionals through journals and granting agencies. Minor-time scientists gave higher influence to departmental colleagues.

Scientists we talked to did not appear very responsive to special interest groups, such as private industry and granting agencies. The scientists seemed to be maximizing utility WRT time and be most interested in producing information that fellow professionals perceived as valuable research and which they found interesting.

It was expected that in Stage II the entrepreneur not only assimilated the demand information but also would determine which outputs he could produce with the available resources. Some possibilities were screened out by resource

Source	Percent[a]
Professionals through journals or conventions	15.6
Departmental colleagues	14.6
Friends who are non-ISU scientists	8.9
Granting agencies	8.2
DEO	7.4
Other	6.5
Adopters of research results	6.3
ISU professors outside the scientist's department	6.1
Regional research committees	5.9
Extension	5.3
ISU Experiment Station administration	5.3
Government contract offers	4.3
Private industry contract offers	2.6
General public, legislators	2.0
Mass media	1.1

[a] The hypothesis H_T: $\mu = 0$ can be rejected for all values at $\alpha = 0.05$.

Table 4. Percent of Scientists Ranking Each Resource Constraint as Very Important, Important, Not Very Important, or Not at All Important

Resource	Very Important	Important	Not too Important	Not at all Important
Graduate students	25.4	25.4	33.3	15.9
Technicians	6.4	20.6	20.6	52.4
Personal interest	60.3	33.3	6.4	0.0
Facilities	55.6	28.6	7.9	7.9
Personal skills, abilities	46.0	44.4	7.9	1.6
Completion time	9.5	28.6	50.8	11.1
Experiment Station funds	17.5	34.9	39.7	7.9
Funds from outside sources	20.6	42.9	30.2	6.5

Table 5. Percent of Scientist Ranking Each Characteristic as Very Important, Important, Not Very Important, Not at All Important

Characteristic	Very Important	Important	Not too Important	Not at all Important
High probability of success	11.1	46.0	38.1	4.8
Intellectually intriguing	39.7	49.2	11.1	0.0
Publishability	31.8	46.0	22.2	0.0
Social Significance	54.0	27.0	11.1	7.9
Familiar method or technique can be used	9.5	36.5	46.0	7.9
Can work in a team	11.1	30.2	47.6	11.1
Can work alone	3.2	15.9	42.9	38.1

sources identified as scarce.

Their own human capital, embodied in their personal interests and research skills, was the resource weighed most heavily in their research decisions. Availability of facilities was also a major consideration. Of least importance as a constraint to research were time needed to complete a project and technicians. The respondents were fairly evenly divided between the importance of experiment station funds. To some scientists projects could not be conducted without these funds whereas others consider the amount of station funds received to be "insignificant." Common adjectives applied to station funds were "constant," "steady," and "certain."

Stage III begins after the scientist has screened research possibilities for demands and resource constraints and is considering only a few fendable ones for formal proposal. The final group of considerations in his choice are closely tied to personal utility or satisfaction expected by the scientist in conducting a particular research investigation. Seven research characteristics were presented and each scientist identified those important in his or her choice. Whether a project was intellectually intriguing or involved an interesting challenge in problem-solving was assigned the highest overall importance. Social significance and publishability were also considerations. Whether a project involved team or solo research, was of least importance in selection.

This study is the first stage in an effort to identify and weight elements in a three-level resource allocation process at agricultural experiment stations. Internal decisionmakers at the scientist level at Iowa State University Experiment Station were interviewed. It seems the decision about allocation of resources to research is made before proposals are written and is influenced most strongly by professional colleagues. It seems opinion leaders among scientists could influence proposals to be responsive to society's needs.

Kaldor repeatedly pointed to the lack of systematic knowledge about the program decision-making process within the experiment station. Primary data on scientist science decisionmaking are scarce. This study attempts to expand this seemingly neglected area in research on research.

Footnotes

1/Jim Hightower, in Hard Tomatoes, Hard Times, accused the land-grant complex of becoming "the sidekick and frequent servant of agriculture's industrialized elite" {3, p. 1}. He concludes that land-grant research has not benefitted and

and rural communities.

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THE CHANGING COST OF PERFORMING AGRICULTURAL RESEARCH:

AN INDEX APPROACH

Joseph W. Murphy and Donald R. Kaldor*

Introduction

Inflation erodes the purchasing power of dollars in every budget in our society. Budgets of agricultural research organizations have been no exception. Inflation has been defined as an increase in the average of prices {1}. A popular indicator of the rate of inflation is the annual percentage change in the Consumer Price Index (CPI) {2}. The CPI is intended to apply to consumer purchases, yet the concept implies that a similar indicator of the annual percentage change in prices of inputs purchased by agricultural research organizations conceivably could be developed.

This paper reports an attempt to develop a quantitative measure of changes in the purchasing power of dollars appropriated from 1973 to 1978 for agricultural research in state agricultural experiment stations (SAES). It is intended to be a complete agricultural research price index, constructed to provide an accurate index for deflating the rising dollar expenditures for agricultural research to constant purchasing power. It is hoped such an index will lead to more accurate forecasting of the rate of increase in the cost of doing research and thus help agricultural science administrators adjust for inflation in budget making and expenditure programming.

Background

Price Indexes

A price index is produced by an averaging process which describes a central tendency of changes in prices of a complex of products. A price index will indicate how much more or less could be purchased of the same combination of inputs but not how the mix should be changed. That is, an index of price level changes does not help to decide how much a research organization should change the conbination of inputs.

The first recorded inquiry into price fluctuations was in 1739 by deFerrace Dutot {3}. In 1923, Irving Fisher produced a major and influential work, The Making of Index Numbers {4}. Three more recently developed published measures of inflation are the Consumer Price Index, the Producer Price Index (formerly known as the Wholesale Price Index), and the Implicit Price Deflators for Gross National Product. Each of these measures averages a different set of prices using a different set of component weights; each produces a different measure of inflation for a different clientele. Yet there is some relationship and correlation among the indices.

None of these price indices may be entirely appropriate for indicating agricultural research cost increases, because none use only the prices of the inputs purchased for agricultural research and none averages the price changes by weighting with the appropriate quantities of inputs for agricultural research. However, the existing published indices might be useful if highly and predictably correlated with changes in agricultural research inputs. If all prices including those for agricultural research inputs moved in the same direction at the same rate, the weights would be unimportant. The extent to which a price index might also serve as an agricultural research cost index can only be known once a good agricultural research cost index is constructed to permit comparison with other indices.

A price index number is relevant for any purchaser of several factors and is only as appropriate as the set of commodities used and the manner in which the set of prices was weighted. The wider the percent variation in price changes, the more important is the choice of weights. Hence, the wider the variation in the mix of purchases among experiment stations, the more critical is the selection of the weights to average the prices. In fact, with wide divergence in both prices and quantities, each station

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of its own. Fortunately, the prices of most agricultural research inputs rise at a similar rate. Furthermore, the variation in expenditure proportions is not great between stations or over time. Thus, a single national index of the cost of performing agricultural research seems feasible and reasonably accurate for all stations.

The derivation of all indices, including an agricultural research cost index, is constrained by accuracy and detail of available data. In the case of this effort, inaccuracy, inconsistency, and incompleteness in the data on prices paid and quantities purchased provided by the 50 SAES reduced somewhat the quality of the index produced. Accounting data on both price and quantity for non-manpower purchases was lacking. Only classification of non-manpower expenditures was possible. This required use of a proxy price index specially weighted by average station expenditure proportions. This substitution made it possible to produce a complete index but one that may have some estimation error or bias that cannot be known or eliminated.

Previous Research Cost Indices

In the 1960s, when research expenditures grew very fast, there was fear that available inflation measures underestimated research cost increases. In the mid-1960s, the first attempt was made to measure the rate of increase in the cost of doing research through indexing. Milton's "Cost-of-Research Index, 1920-1965," Research Analysis Corporation {5}, measured the change in the cost of research by averaging among research agencies the dollars spent per technical manyear employed in research and development. Data were gathered from various research institutes in the United States. The technical manyear cost was derived by dividing the total annual cost of each particular R&D organization participating in this study by the number of scientific and technical personnel working in the organization. Milton's "cost per manyear" increased over time not only because the salaries of scientists increased, which they did, but also because the quantity of non-manpower inputs per scientist increased as did their prices. The partitioning of the total cost increases to each source was not possible in this study. Milton concluded that while research and development expenditure had increased at 15% per year, the technical years of input have been increasing at only 5% per year. It may be concluded that Milton did not construct a research input price index but estimated only the average total cost per technical person employed.

In 1966, Roland R. Robinson wrote "Estimating the Real Level of Support Given to Research Programs at the State Agricultural Experiment increases in science years employed. His effort, although still not a complete cost index, was an improvement over Milton's method. Robinson derived a cost inflation measure for one input, agricultural research manpower, by estimating across stations an average manpower cost per professional manager employed. Robinson found that the accuracy of his attempt was constrained by lack of detailed data. Expenditure prices and quantities for subcategories of manpower, *i.e.*, professors, assistant professors, etc., were not explicitly available to Robinson. As in 1966, it is still difficult to determine the rate of shift in the mix of these subcategories of agricultural researchers, which is important to do. A shift in the mix toward lower paid assistant professors would appear as a decrease in average price of manpower and depress the index estimating the effect of inflation. Conversely, some increases in cost per science year experienced by some stations could result from losing and not replacing younger professors with lower salaries.

In 1972, the National Science Foundation (NSF) published the report, "A Price Index for Deflation of Academic R&D Expenditures" {7}. The report states that the index for each year indicates what "dollar levels of R&D support correspond to employment of a given number of scientists or engineers, but other factors ought not be ignored" (p. 5). Hence a non-manpower component was not included so that the NSF index does not fully indicate what it will cost to finance a given level of research effort in year *t* relative to the same research effort in year t-1. If the relative prices among manpower inputs change, then research procedures might also change. Contrarily, as new research techniques are employed then the most productive mix of personnel, supplies, and equipment would also likely change. In principle, a manpower price index like NSF constructed cannot answer the question of dollars needed to maintain constant output.

The NSF study provides an important parallel and some conceptual assistance in the construction and development of a cost of research index for SAES. NSF tested an index constructed as a weighted average of year-to-year manpower price relatives. Average salary changes at each institution were weighted by base year proportion of all salaries in that institution. The aggregated form of the NSF price index is:

$$(1) \quad NSF = \sum_{j=1}^{n} \alpha_j \cdot \frac{P_1}{P_o}$$

$\overline{P_o}$. To obtain the average over several institutions, each percent salary change is weighted by the relative size of the institution (α_j):

$$(2) \quad \alpha_j = \frac{P_{oj}\, q_{oj}}{\sum_{j=1}^{n} P_{oj}\, q_{oj}}$$

The NSF study made progress in indexing research cost. The NSF study was the first to categorize manpower, and by this strategy reduced inaccuracy resulting from shifting mix between scientists and support personnel. NSF manpower categories transformed nicely to the manpower divisions available from USDA Form AD-419: scientists (241), professional support (242), technical support (243), and clerical and other support (244). The agricultural manpower index in this study includes a fifth manpower division, administrative (245). Adding the administrative category further reduces the salary heterogeneity in the scientist category. The NSF study supported our hypothesis that heterogeneity of each input category should be minimized to increase accuracy.

An improvement that may be made in the NSF index is the addition of fringe benefits. Approximately 20% of institutional manpower expenditures today are fringe benefits. Expenditures for manpower by institutions each successive year are including proportionately larger fringe benefits. Legislatures, budget committees and collective bargainers are wrestling with wage-price guidelines, trying to increase after-tax real income in the face of higher nominal tax rates with inflation. Today, they often prefer increases in the form of increased fringe benefits.

The Agricultural Research Cost Index

The persistent constraint in constructing an accurate research cost index has been the lack of price and quantity information for each homogeneous subcategory of expenditures, both for manpower and non-manpower. Hence, consideration of these data are presented first. The model development then follows.

Data Characteristics

In 1977, each of the 55 SAES was asked to supply manpower expenditures and employment data by categories for the fiscal years 1973 to 1976. Each station was also asked to provide data about non-manpower expenditures. Responses were obtained from 20 stations--10 provided complete sample of 14 in the latter year. For the years 1977 and 1978, the response increased significantly, 25 stations providing data about manpower for fiscal year 1978. The reports submitted in 1979 for 1978 were considered to be accurate and highly reliable.

Investigation of "suspicious" data was conducted through direct communication with administrators and accountants of individual SAES. The stations cooperated to the extent of available resources and provided answers to numerous questions. For example, the data for one station were extremely orderly and well behaved. The expenditure by category had been estimated from staff numbers and percent salary increase. The station did not have available the actual expenditures by subcategory needed to respond to the survey format but nevertheless provided estimates. The estimates were uncharacteristically orderly, whereas the empirical data set was not.

In the first year, there were surprises in the data as initially received or as it was processed into time series of average prices. Likewise, the data provided for 1974 to 1976 resulted in average prices and the percentage change in prices moving in unexpected directions (see Table 1).

TABLE 1.

Average Scientific Manpower Prices
for One Station

Fiscal Year	Average Price	Change	Scientist Years
1973	$28,354.00		169.4
1974	$26,425.00	-6.8%	178.7
1975	$29,988.00	+13.5%	164.8
1976	$28,900.00	-3.6%	205.3

If professors (category 241) are reasonably homogeneous, the average price would not be affected by changing the number of professors. However, if full professors are paid more than associates and the mix changes, as it does over time, the average price may fall even though every professor gets a raise. In practice, the observed percent change in average price and the index number confounds the effect of price changes when the mix changes. Thus, if there are heterogenous subcategories and a change in mix within subcategory, the index number change does not indicate a movement in the price alone. However, if the mix is assumed stable, then the average price fell in 1974 by approximately 7%, an unlikely movement, especially if compared to to be investigated before including the simple relative prices from a station and subcategory in the index construction.

It may be that the weighted average of estimated percent salary change by subcategory of professor would provide an accurate index.

The non-manpower data, which account for approximately 29% of total costs, presented a vexing indexing problem. It was impossible to derive an average price for any non-manpower subcategory. Non-manpower data supplied by 33 stations were examined. Many stations with usable data for one subcategory of non-manpower inputs had none for other subcategories. However, the non-manpower data did provide enough categorization that proportions of expenditure by subcategory or relative expenditure weights could be derived. Thus, if from another source an appropriate index for change in prices by subcategory was available, the relative expenditure weights could be employed to construct an index for non-manpower. Expenditure weights from the sample were as much as could be provided from the existing data. An aggregate cost of agricultural research index would have to use non-SAES sources to estimate non-manpower price changes.

Administrative manpower is the smallest category with the highest average price and the most reporting inconsistencies. To identify "unusual" quantities of administrative manpower, we related variation in the number of administrative years with variation in scientist years among the stations by using simple linear regression, forcing the regression line through the origin.

There is a loose but significant relationship between the number of administrative years ($\hat{AY}$) employed and the number of scientist years (SY) employed according to 1978 SAES data (equation 3).

$$(3) \qquad \hat{AY}_{78} = .05\ SY_{78}$$

$$\text{s.e.} = .0099 \qquad F = 25.03$$

$$t = 5.0 \qquad R^2 = .532$$

Regression equation (4) shows similar results with 1976 data.

$$(4) \qquad \hat{AY}_{76} = .0495\ SY_{76}$$

$$\text{s.e.} = .0135 \qquad F = 13.43$$

$$t = 3.67 \qquad R^2 = .4897$$

varies from a maximum of one to six to a minimum of one to 85. One possible explanation for this wide range of variation is that the definition of "administrator" was interpreted differently and more or less inclusive by the various stations.

Since only approximately 50% of the variation in administrative years is explained by the variation in scientist years employed, we conclude that additional factors are involved.

Model Development

Our index of the cost of performing Agricultural Research (ARI) consists of two components: manpower (I_m) and non-manpower (I_n). These two components, weighted by their relative expenditures, produce the complete index number:

$$ARI = .715\ I_m + .285\ I_n$$

To construct the manpower index requires only two data inputs: (1) the expenditures for the five categories of manpower for each station for each year and (2) the quantities of manpower for each category for each station for each year. Alternative formulae for calculating index numbers with different weighting strategies were tested.

Our index calculation strategy presented here is similar to the NSF index. First, manpower expenditures (e_{ij}) and employee years (m_{ij}) were summed across stations within manpower category j to obtain sample totals and a sample average price ap_j for employee category j:

$$ap_j = \frac{\sum_{i=1}^{n} e_{ij}}{\sum_{i=1}^{n} m_{ij}}$$

where e_{ij} = the manpower expenditure by the i^{th} station for the j^{th} employee category, (i=1,.....,25)

m_{ij} = the number of employee-years devoted by the i^{th} station to the j^{th} employee category, (i=1,.....,25)

ap_j = the average price of the j^{th} employee category for the sample of n stations, (j=1,.....,5)

A sample average cost per unit of manpower was calculated for each category of manpower for each year. These sample average costs are estimates of total agricultural research system cost per

Table 3 presents cost indices for each manpower category. The indices are derived by dividing the observed average cost by the 1976 average cost for the j^{th} employee category. Table 4 indicates the rate of cost change is larger in the administrative manpower category than in others. Scientists' salaries change at the slowest rate.

average prices of Table 2 and the proportion of total expenditures by category for 1976 from Table 5. That is:

$$AP_m = \sum_{j=1}^{5} \frac{\sum_{i}^{25} e_{ij}}{\sum_{i}^{25} m_{ij}} \times \frac{\sum_{i}^{25} e_{ij}}{\sum_{i}^{25} \sum_{j}^{5} e_{ij}}$$

Table 2. Sample Average Cost per Employee Category, 1973-1978

Fiscal Year	n	241	242	243	244	245	AP_m
1973	12	$22,050	$ 8,561	$ 7,624	$ 7,284	$21,334	$15,205
1974	13	22,746	9,031	8,125	7,503	22,169	15,764
1975	14	24,550	10,353	8,467	8,490	20,092	16,937
1976	16	25,690	11,180	9,458	9,027	27,359	18,175
1977	23	26,662	11,826	10,241	9,725	28,396	19,209
1978	25	28,552	12,769	11,041	9,987	35,420	20,550

Table 3. Cost Index of Manpower Categories, 1973-1978 (1976=100)

Years	Scientists 241	Professional 242	Technical 243	Clerical 244	Administrative 245
1973	83.1	84.2	78.9	77.8	82.8
1974	86.7	87.7	85.00	81.6	84.5
1975	93.2	94.2	88.1	93.2	90.0
1976	100.0	100.0	100.0	100.0	100.0
1977	104.7	110.0	108.5	109.4	111.4
1978	110.6	118.6	115.9	110.2	138.9

To obtain the average rate of inflation in agricultural research manpower cost the five categories must be averaged. The scientists category contains nearly half of the expenditures (see Table 5) because it has the large number of highest cost personnel.

Table 4. Average Annual Rate of Inflation of Costs of Manpower by Category 1973-78

Category	Average Annual Rate of Inflation
Scientists	5.9
Professional	7.1
Technical	8.0
Clerical	7.2
Administrative	10.9

which states that the sample average price per person for all manpower (Table 6) equals sample average cost per category (Table 2, row 4) times category portion of 1976 manpower expenditure (Table 5, all rows). The sample average weights do not vary widely among years nor does the proportion of expenditure by employee category vary widely among stations.

The average cost for all manpower by years (Table 6) shows a rate of increase or inflation of 6.7%. That is intermediate among the rates of inflation for individual manpower categories.

The non-manpower index requires an averaging and then an indexing of prices of a category of expenditures by SAES. The non-manpower component is comprised of a very heterogeneous group of inputs. The inputs can be categorized into four to eight groups based on homogeneity of

Fiscal Year	Sample Size	241	242	243	244	245
1974	13	.473	.114	.198	.171	.035
1975	14	.472	.137	.187	.174	.039
1976	16	.479	.130	.185	.165	.043
Average (1974-76)		.475	.127	.189	.170	.039
1977	22	.437	.161	.195	.179	.028
1978	23	.432	.165	.202	.175	.027

Table 6. Average Cost per Unit of All Manpower in Agricultural Research, Index of Agricultural Research Manpower Cost and Percent Change per Year in Agricultural Research Manpower Cost

Fiscal Year	Average Cost AP_m Dollars	Manpower Index I_m 1976 = 100	Annual Change in Manpower Cost from Previous Year Percent
1973	15,205	83.7	---
1974	15,764	86.7	3.6
1975	16,937	93.2	7.5
1976	18,175	100	7.3
1977	19,029	104.7	4.7
1978	20,550	113.1	8.0

characteristics. The non-manpower expenditure data were initially classified into eight subcategories: (1) travel, (2) supplies, (3) equipment, (4) utilities, (5) land and structures, (6) communications, (7) repair and maintenance, and (8) miscellaneous. A proxy price index was used for each subcategory. Existing price indices were found that would approximate the subcategories. For example, in the transportation industry, railroads compute unweighted relative year-to-year expenditures by subcategory. However, this procedure would measure how much prices had increased only if physical volume remained constant. If the mix changed, such year-to-year percent change in expenditure would not indicate price changes because they are not price indices. An investigation of indices produced by the Bureau of Labor Statistics revealed subcategories similar in content to only some of the seven subcategories. Thus, the original seven non-manpower subcategories had to be reduced to four.

The most appropriate proxy price indices were selected by comparing definitions with the subcategories of non-manpower purchases. The final set of proxies is:

Subcategory	Proxy Component	Index
Travel	Transportation Services	CPI
Supplies	Commodities Less Food, Non-durable	CPI
Equipment	Machinery & Equipment	PPI
Utilities	Fuels & Other Utilities	CPI
Other	Other Goods & Services	CPI

The cost indices (Table 7), acting as proxies or substitutes for the unavailable non-manpower subcategory average costs, were combined into a single weighted average non-manpower price index. The weights (Table 8) for non-manpower are the sample proportion of expenditures in each non-manpower category. Supplies is the most important category with 35.2% of non-manpower expenditures. In spite of the great concern for rising utility prices, that subcategory represents only 2.8% of non-manpower station expenditure. Travel also is a closely watched expenditure but represents only 6.7% of non-manpower expenditure. All non-manpower

The final step in the derivation and subsequent computation of the cost of an agricultural research index is to average the manpower and non-manpower indices. The results of the computations are shown in Table 9 for 1973 through 1978.

The index of agricultural research cost is the weighted average of manpower and non-manpower prices indices. The weights are the 1973 through 1976 sample proportion of expenditures in each (Table 10), using either the average weight or the 1976 weight.

change in the ARI index number with the rate of change in the unadjusted CPI for all items, state and local government purchases of goods and services, and the GNP deflator. The cost of performing agricultural research has risen from 1973 to 1978 by 6.3% but has risen less rapidly than prices in general (8 to 10%). Rates of inflation as measured by the three national measures are larger over the period than the Agricultural Research Index (ARI) number.

Table 7. Proxy Cost Index Numbers 1973 Through 1978 for Non-manpower Subcategories for June-July Fiscal Year

Subcategory	1973	1974	1975	1976	1977	1978
Travel	78.5	81.4	87.6	100.0	108.1	110.8
Supplies	78.8	89.0	95.8	100.0	105.2	107.4
Equipment	71.2	81.5	94.4	100.0	106.3	114.6
Utilities	69.5	82.2	91.8	100.0	110.7	114.7
Other	81.4	87.3	94.6	100.0	105.8	109.0

Table 8. Sample Expenditure Proportions by Non-manpower Subcategories, 1973-1976

Fiscal Year	Air & Auto Travel	Office & Laboratory Supplies	Capital/ Equipment	Utilities	Other[a]
1973	.067	.339	.201	.024	.367
1974	.064	.363	.223	.024	.326
1975	.067	.356	.230	.029	.318
1976	.070	.348	.203	.033	.346
Average	.067	.352	.214	.028	.339

[a] Includes telephone, animal feed, fertilizer, computer service, land and structures.

Table 9. Estimated Cost Indices for Manpower, Non-manpower and Total Research Cost

Fiscal Year	Manpower	Non-manpower	Research Cost
1973	83.7	77.8	82.0
1974	86.7	86.1	86.5
1975	93.2	94.3	93.5
1976	100	100.0	100
1977	104.7	105.9	105.0
1978	113.1	109.7	112.1

Table 10. Expenditure Proportions for the Sample and Four-year Average Used as Relative Weights Between Manpower and Non-manpower, 1973-76

	n	Manpower	Non-manpower
1973	27	.719	.281
1974	27	.7065	.2935
1975	31	.707	.293
1976	33	.715	.285
Average		.711875	.288125

penditures with the ARI deflated expenditures for all SAES in 1973-1978. Actual expenditures are available in the Inventory of Agricultural Research (Volume III, Table IV-E-6). As indicated in Table 12, substantial growth in agricultural research dollar expenditures by SAES occurred in each year. Expenditures in real terms also increased over the period. However, the expenditures in current dollars increased more rapidly than expenditures in real terms, resulting from the rise in input costs.

Conclusions

The study examines changes in SAES input costs from 1973 through 1978. From data reported by a sample of stations a cost index was derived for manpower and non-manpower inputs. Funds to agricultural research increased steadily over the period but the level of effort changed eratically. Inputs cost changes for agricultural research are not the same as other measures of inflation.

We estimate that the cost of performing agricultural research rose 6.3% per year from 1973-78 which is less than the cost of purchases by state fact that scientists compensation rose at only 5.9% per year while the CPI increased 7.9% per year in the same period.

The availability of an agricultural research index permits evaluation of the need for it. This study demonstrates that it is technically feasible to construct such an index. Also, it has shown that there does not seem to be a close functional relationship between changes in agricultural research costs and other measures of inflation. Tentatively, it seems that the average cost of manpower by category is the most valuable and the least cost component of the cost of the agricultural research index.

References

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Table 11. Comparison of Aggregate Agricultural Research Index Rate of Inflation With Other Published Series Rates

Index	73-74	74-75	75-76	76-77	77-78	Avg.
CPI: All items	8.9	11.1	7.1	5.8	6.8	(7.9)
ARI	5.5	8.1	7.0	5.0	6.8	(7.4)
Producer Price Index: All Commodities	16.1	16.9	5.3	5.4	6.2	(10.0)
State & Local Government	7.7	10.5	6.7	7.0	7.8	(8.1)

Table 12. Actual Deflated Expenditures by State Agricultural Experiment Station 1973 Through 1978

Fiscal Year	Actual Expenditures ($ Mil.)	Percent Change	Deflated Expenditures ($ Mil.)	Percent Change
1973	385	--	460	--
1974	415	7.8	480	4.3
1975	480	15.7	525	9.4
1976	525	9.4	525	0.0
1977	585	11.4	570	8.6
1978	653	11.6	590	3.5

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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

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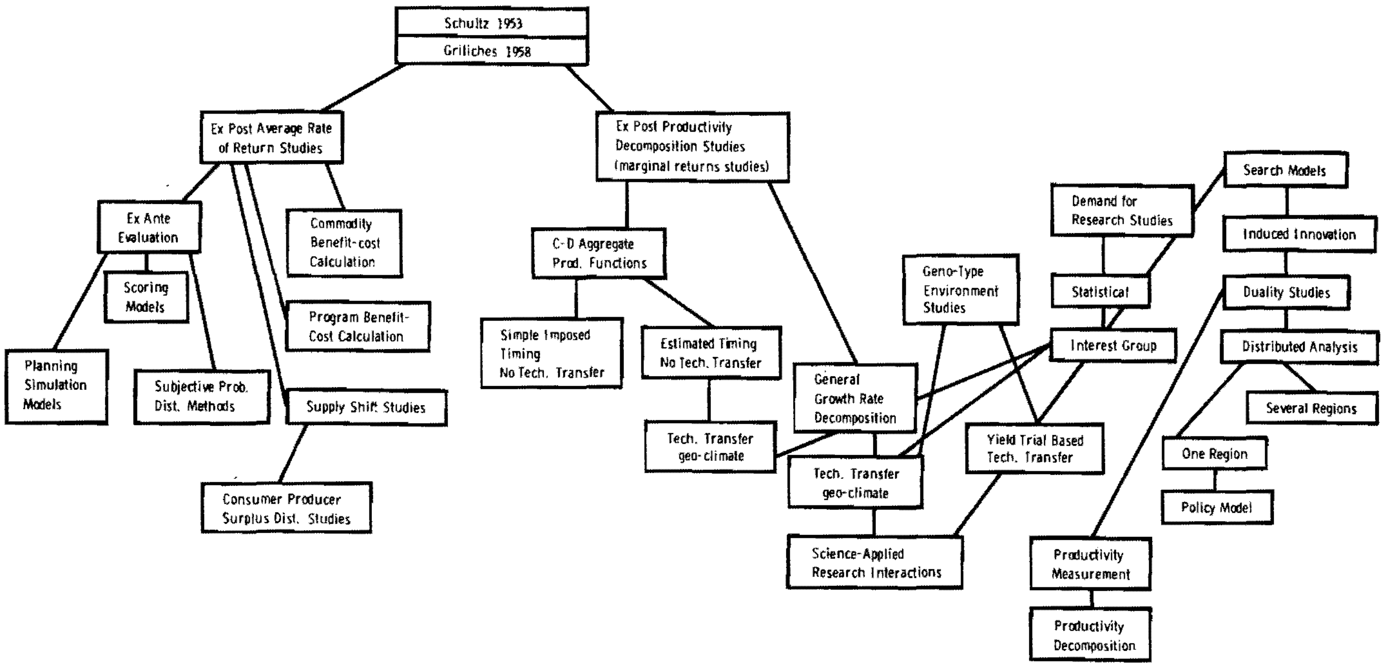


possible economic outcomes from research programs have been developed. They may tell us something about different effects of research given that one knows what the research program is likely to produce but are not suited to real ex ante evaluation. (I also include other policy models in the right-most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

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 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.

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.

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 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.

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

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 $S_0 - S_{10}$.

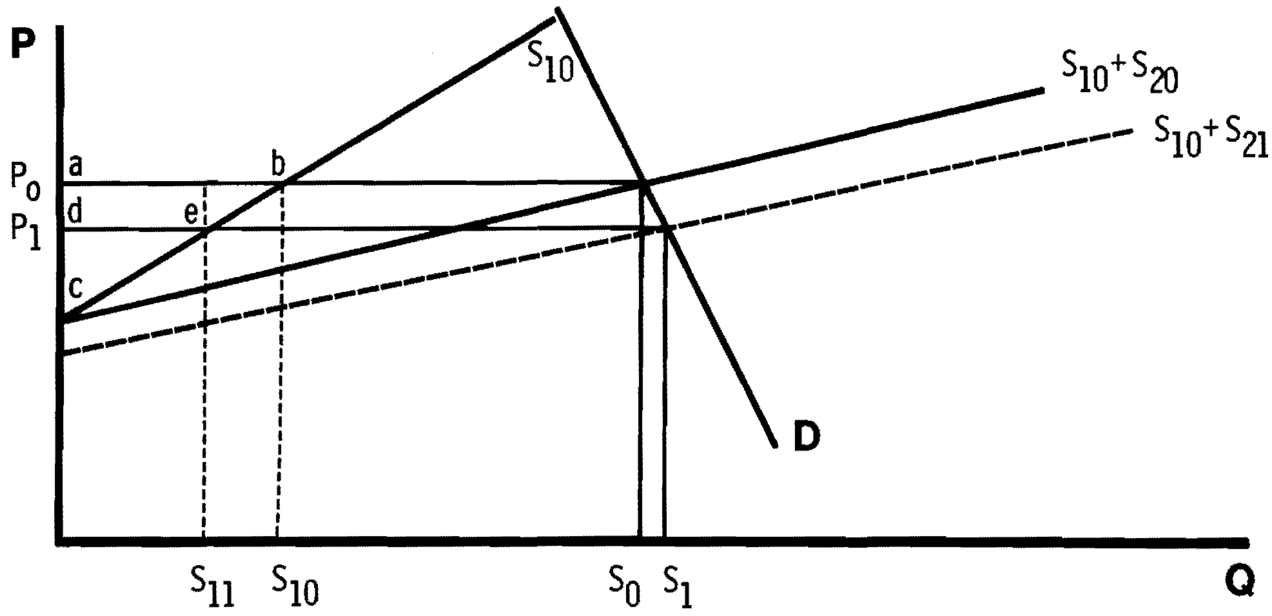
Now, suppose that research results are available only to group 2 producers. This will shift the aggregate supply curve to $S_{10} + S_{21}$. Market price will fall to P_1 and group 1 suppliers will factors to producers in group 1 unequivocally fall (the area abde). Rents to producers in group 2 may increase (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.



duce 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...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

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

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

(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

$\left[\eta_{ij}\right] = \left[\frac{\partial Y_i}{\partial P_i} \; \frac{P_j}{Y_i}\right]$ 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

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

$$\sum_{ik}\sum b_{ik}(\ln P_i) \; (\ln Z_k) + \sum_i b_{it}(\ln P_i)t$$

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

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

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

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

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

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

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

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

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

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 guishing 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

vasiveness 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

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

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

The research index used in estimation is of the form

$$IR_K = \theta\,(R_K + 0R'_K)$$

where R'_K indicates the stock of research in similar regions or subregions outside the state and 0, 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 ith 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 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 ith 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 0, 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

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

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 = ϕ (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.

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

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

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

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

	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

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

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

$$\left.\begin{aligned} E_i' &= \frac{\partial X_i}{\partial t}\frac{1}{X_i} \\ E_Y' &= \frac{\partial Y}{\partial t}\frac{1}{Y} \end{aligned}\right\} =$$ 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

$$(4)\quad \begin{aligned} L' &= \varepsilon_L W' + L^* \\ K' &= \varepsilon_K R' + K^* \\ Y' &= \alpha P' + D^* \end{aligned}$$

where $\varepsilon_i (\geq 0)$ is a factor supply elasticity, $\alpha (\leq 0)$ 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

$$\begin{bmatrix} \beta_{KL} & \beta_{KK}-\varepsilon_K & \beta_{KY} \\ \beta_{YL} & \beta_{YK} & \beta_{YY}-\alpha \end{bmatrix} \begin{bmatrix} R' \\ P' \end{bmatrix} = \begin{bmatrix} K^* & -Z^* & -E'_K \\ D^* & -Z^* & -E'_Y \end{bmatrix}$$

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

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

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

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

$$(28)\quad \left.\frac{\partial P'}{\partial A_L'}\right|_{\text{LK bias}} \underset{<}{\geq} 0$$

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

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)

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

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

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

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

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

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

and the subscripts 1 and 2 refer to the regions.

From (30) we cam gather that

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

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

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

$$(34)\quad \frac{\partial W'}{\partial Z_r^*} \underset{>}{\leq} 0$$

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

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

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

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

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

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

(40)

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

$$- \nu_1 E_{Y2}' - \nu_2 E_{Y2}'$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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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THE EVALUATION OF INDUSTRIAL RESEARCH AND DEVELOPMENT PROJECTS

Edwin Mansfield*

Introduction

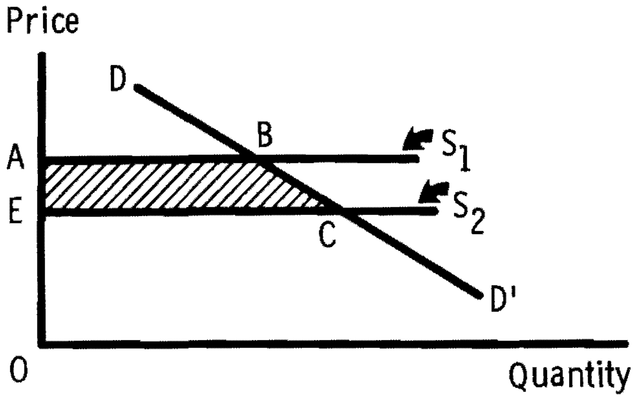
Considerable work has been carried out by economists, engineers, and others to formulate and study methods to evaluate industrial research and development R & D projects. In this paper, my purposes are (1) to describe the results of recent studies to measure (ex post) the social benefits from industrial innovations, (2) to indicate the sorts of ex ante evaluation techniques described in the literature and the extent to which they are used by American firms, (3) to provide measures of the biases and errors contained in ex ante estimates of development cost, development time, and the profitability of new processes and products, and (4) to indicate the effects on probabilities of success of how quickly ex ante economic evaluations are made.

Measurement of Social Benefits from Industrial Innovations

Any innovation, particularly a major one, has effects on many firms and industries, and it obviously is difficult to evaluate each one and sum them up properly. Nonetheless, economists have devised techniques that should provide at least rough estimates of the social rate of return from particular innovations, assuming that the innovations can be regarded as basically resource saving in nature.

To estimate the social benefits from an innovation, economists have used a model of the following sort. If the innovation results in a shift downward in the supply curve for a product (such as from S_1 and S_2 in Figure 1), they have used the area under the product's demand curve (DD') between the two supply curves--that is, ABCE in Figure 1--as a measure of the social benefit during the relevant time period from the innovation. If all other prices remain constant, this area equals the social value of the additional quantity of the product plus the social value of the resources saved as a consequence of the innovation. Thus, if one compares the stream of R & D (and other) inputs relating to the innovation with the stream of social benefits measured in this way, it is possible to estimate the social rate of return from the investment in the innovation.

Figure 1. Measurement of Social Benefits from Techological Innovation



Recently, a study was made by Mansfield, Rapoport, Romeo, Wagner, and Beardsley (in Mansfield, et al. 1977) of the returns from 17 specific industrial innovations. These innovations occurred in a variety of industries, including primary metals, machine tools, industrial controls, construction, drilling, paper, thread, heating equipment, electronics, chemicals, and household cleaners. They occurred in firms of quite different sizes. Most of them are of average or routine importance, not major

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*Professor of Economics, University of Pennsylvania. The research on which this paper is based was supported by grants from the National Science Foundation, which, of course, is not responsible for the views expressed here. This paper draws heavily on Mansfield (1976a), Mansfield (1976b), Beardsley and Mansfield (1978), and Mansfield and Wagner (1975). Much of this paper is taken directly from these earlier papers.

indication that it is biased toward very profitable innovations (socially or privately) or relatively unprofitable ones.

To obtain social rates of return from the investments in each of these innovations, my colleagues and I used a model somewhat like that described in Figure 1, except that we extended the analysis to include the pricing behavior of the innovator, the effects on displaced products, and the costs of uncommercialized R & D and of R & D done outside the innovating organization. The results indicate that the median social rate of return from the investment in these innovations was 56%, a very high figure. On the other hand, the median private rate of return was 25%.

Table 1. Typical Expenditure on an R & D Project before Studies of Market and Profit Potential, 16 Firms.

Expenditures ($000)	Number of Firms
Less than 10	7
10 - 24	3
25 - 49	1
50 - 99	2
100 - 149	1
150 - 199	1
200 and over	1
Total	16

In addition, my colleagues and I obtained very rich and detailed data concerning the returns from the innovative activities (from 1960 to 1972) of one of the nation's largest firms. For each year, this firm has made a careful inventory of the technological innovations arising from its R & D and related activities, and it has made detailed estimates of the effect of each of these innovations on its profit stream. We commputed the average rate or return from this firm's total investment in innovative activities during 1960-72, the result being 19%, which is not too different from the median private rate of return given in the previous paragraph. Also, we computed lower bounds for the social rate of return from the firm's investment, and found that they were about double its private rate of return, which also agrees with the results in the previous paragraph.

The foregoing results pertain to the average rate of return. In earlier investigations based Mansfield ([illegible]) and Minasian ([illegible]) estimated the marginal rate of return from R & D in the chemical and petroleum industries. Mansfield's results indicated that the marginal rate of return was about 40% or more in the petroleum industry, and about 30% in the chemical industry if technical change was capital embodied (but much less if it was disembodied). Minasian's results indicated about a 50% marginal rate of return on investment in R & D in the chemical industry.

In a more recent study, Terleckyj (1974) has used econometric techniques to analyze the effects of R & D expenditures on productivity change in 33 manufacturing and nonmanufacturing industries during 1948-66. In manufacturing, the results seem to indicate about a 30% rate of return from an industry's R & D based only on the effects of an industry's R & D on its own productivity. In addition, his findings show a very substantial effect of an industry's R & D on productivity growth in other industries, resulting in a social rate of return greatly exceeding that of 30%. No evidence was found, however, demonstrating that government contract R & D has any effect on the productivity increase of the industries performing it.

Griliches (1975) has carried out an econometric study, based on data for almost 900 firms, to estimate the rate of return from R & D in manufacturing. His results pertain only to the private, not the social, rate of return. He finds that the private rate of return is about 17%. It is much higher than this in chemicals and petroleum, and much lower than this in aircraft and electrical equipment. He finds that the returns from R & D seem to be lower in industries where much R & D is federally financed.

Based on computations for the economy as a whole, Denison concluded that the rate of return from R & D was about the same as the rate of return from investment in capital goods. His estimate of the returns from R & D was lower than the estimates of other investigators, perhaps due to his assumptions regarding lags. In his presidential address to the American Economic Association Fellner estimated the average social rate of return from technological-progress activities, his conclusion being that it is "substantially in excess" of 13 or 18%, depending on the cost base, and that this is much higher than the marginal rate of return from physical investment at a more or less given level of knowledge.

To sum up, practically all of the studies carried out to date indicate that the average social rate of return from industrial R & D in the neighborhood of 30 - 50%. Of course, there is a variety of very important problems and limitations inherent in each of these studies. Certainly, they are very frail reeds on which to base policy conclusions. But recognizing this fact, it nonetheless is remarkable that so many independent studies based on so many types of data result in so consistent a set of conclusions.

Models for R and D Project Selection

Economists and operations researchers have devoted considerable attention to R & D project selection. A variety of models have been developed to help solve this problem. These models vary enormously in sophistication, some relying on the crudest sorts of ranking procedures, some employing fairly straightforward adaptations of capital budgeting techniques, some using linear programing, some using dynamic programing, and some using Bayesian decision theory. Among the best known of these techniques are PROFILE (Programmed Functional Indices for Laboratory Evaluation) and QUEST (Quantitative Utility Estimates for Science and Technology), both of which were developed for the U.S. Navy, and PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers), developed by Honeywell. (See Cetron et al. 1969.)

For present purposes, it is sufficient to present a relatively simple programing model to illustrate the nature of such techniques. Suppose that a firm has a list of n possible R & D projects that it might carry out and that i^{th} project would cost C_i dollars to carry out. Moreover, the i^{th} project is estimated to have a probability of success of P_i, and if successful, it will result in a profit (gross of R and D costs) of π_i. Then, if the firm can spend no more than C dollars on R & D, its problems can be represented as follows:

Maximize $$\sum_{i=1}^{n} x_i(P_i\pi_i - C_i).$$

where $$\sum_{i=1}^{n} x_iC_i \leq C$$

and $$x_i = 0, 1.$$

In other words, the firm's problem is to choose the X_i--where $X_i = 1$ if the i^{th} project is accepted and 0 if it is rejected--in such a way that the expected value of profit is maximized, subject to the constraint that the total amount spent on R & D be no more than C. This, of course, is an integer programing problem. (See Freeman, 1960.)

Of course, this is a relatively simple model. parameters of the probability distribution of profit other than the expected value. It is possible to recognize that, in most cases, there is a variety of expenditure levels at which a project can be carried out. It is possible to recognize that the impact of one project may depend on the outcome of another project. If one is willing to cope with the complexities and data requirements that result, it is possible to extend this model in many directions. But for present purposes, this simple model is a suitable illustration.

The Application of Project Selection Models

It is difficult to measure with accuracy the extent to which project selection models of this sort are being used in the United States. Our own surveys indicate that a large proportion of the laboratories--particularly the larger laboratories--in the chemical, drug, and electronics industries are using some form of quantitative project selection technique. But it is difficult to tell how significant such techniques are in the decisionmaking process. In some laboratories, they are taken much more seriously than in others. Indeed, one suspects strongly that in some laboratories these techniques are little more than window dressing, the real determinants of project selection professional hunch, intrafirm politics, as well as a host of other factors being at work behind the facade.

However, one thing appears to be clear: the more sophisticated types of models are not being used very extensively. For example, Cetron and Ralph report that only 20% of the firms responding to their survey had tested or used linear programing models and that only about 10% had tested or used more complicated techniques like PROFILE, QUEST, or PATTERN. And for a variety of reasons, I suspect that these figures are overestimates for American industry as a whole. In the American government, there has been considerable attention devoted to such models, particularly in the Department of Defense. But it is difficult to tell with any certainty the extent to which these models have actually been applied.

There are a number of reasons why the more sophisticated models have not found extensive use. First, even the more sophisticated models are often oversimplified in important respects. For example, many models fail to recognize that R & D is a process of buying information, that unsuccessful projects can provide much valuable information, and that the problem is one of sequential decisionmaking under uncertainty. Thus, they fall into the sorts of traps that the RAND studies of military R & D describe so well. Second, application of the more sophisticated models about $250,000 and that the cost of maintaining the model is about $50,000 per year. Needless to say, many techniques do not cost nearly this much, but they are far from costless. Third, and perhaps most important, these models are based on estimates that are not very reliable, as we shall see in the following section.

Accuracy of Estimates of Development Cost and Time

Practically any project selection model requires estimates of the cost of carrying out a prospective R & D project, and the time that it will take. Unfortunately, these estimates tend to be quite inaccurate. In the military field, it is well known that there tend to be large overruns in R & D costs and lesser overruns in R & D time. For example, Peck and Scherer found that for a sample of 12 airplane and missle development projects, the average ratio of actual to estimated cost was 3.2, and the average ratio of actual to estimated time was 1.4. In civilian fields, there seems to be more optimism concerning the accuracy of these estimates, with a surprising number of R & D managers regarding such estimates as good or excellent. However, the available evidence indicates that these estimates are almost as bad for civilian as for military work when reasonably large technical advances are attempted.

Even when firms doing commercial work attempt relatively minor advances, these estimates tend to be considerably wide of the mark. For example, in a proprietary drug firm we studied, the average ratio of actual to estimated development cost was 2.1 and the average ratio of actual to estimated development time was 2.9. Moreover, the standard deviation of the cost ratio was 3.2, and the standard deviation of the time ratio was 1.6. Clearly, these estimates of development cost and time were quite inaccurate. Studies of the accuracy of estimates of the probability of technical success indicate that they too are not very trustworthy. For example, in the proprietary drug firm cited above, although the estimated probabilities of technical completion are of some use in predicting which projects will be completed and which will not, they are not of much use. (See Mansfield et al. (1971).)

Given the large biases and errors in the estimates that are used in project selection models, it is no wonder that managers have not been quick to adopt them. Indeed, as noted above, there is some evidence that managers may be more optimistic than they have a right to be about the accuracy of some of these estimates. If they had a better idea of how bad these estimates tended to be, they might be even more reluctant to place heavy dependence on them. With regard to these errors and biases, it should be noted that, to a

close one's eyes to the fact that these estimates are used to allocate the firm's resources. Consciously or unconsciously, cost and time estimates may be biased downward--and estimates of the value of research results may be biased upward--to "sell" projects to management. This factor, as well as the uncertainties inherent in research and development, is responsible for the large errors in these estimates.

Accuracy of Industrial Forecasts of the Profitability of New Products and Processes

Very little information is available concerning the accuracy of estimates of the profitability of investments in new products and processes. In a recent study, Beardsley and I (1978) presented detailed empirical results on this score concerning all of the major innovations developed by one of the nation's largest firms in 1960-64. Because these data have been systematically and carefully updated by the firm, they provide a relatively unique opportunity to study how quickly forecasts of this sort converge on their true value.

These data indicate that the initial estimates of the profitability of a new product or a new process are no more reliable than forecasts of development cost and time. This is not because of inadequate forecasting or analytical work on the part of the firm studied here. Based on all available indications, this firm is among the more competent in this regard in the country. Instead, these results reflect the inherent uncertainty involved in estimating the profitability of an innovation.

Second, our results indicate that it takes four or five years after the development of a new product or process before this firm can estimate reasonably well the discounted profits from the innovation. Undoubtedly, this length of time varies from firm to firm, and we cannot be sure that this firm is typical in this regard. But to the extent that it is typical, potential innovators must reckon on relatively long periods of time when they will be unable to tell with much accuracy whether it was wise or foolish to have developed a particular new process or product. Obviously, this makes life difficult for a potential innovator, who would like to buy information concerning success or failure quickly and cheaply.

Third, in this firm at least, there seem to be large forecasting errors both for new processes and new products, and how long it takes after the new technology is developed to estimate the discounted profits reasonably well does not seem to vary much between new products and new processes. This may seem surprising, since one and the public. But it must be recognized that the firm finds it difficult to forecast future input prices, royalty receipts, and a variety of other factors influencing the profitability of a new process.

Fourth, and perhaps most interesting from the point of view of public policy, there seems to be a tendency for this firm (and others as well) to underestimate the profitability of very profitable innovations and to overestimate the profitability of relatively unprofitable innovations. In part, this seems to stem from the belief by the forecasters that the penalties for being conservative in their estimates are less than those for being too far out on a limb (particularly in an upward direction). In general, but perhaps not in the case of this firm, this reduction in the forecasted increment between the discounted profits from the expected "big winners" and the more run-of-the-mill innovations may result in a distorted allocation of resources. Because the extra profits to be obtained from the expected big winners are underestimated, many of them may not be carried out on as big a scale or as quickly as would seem justified if the forecasts were unbiased in this regard.

Economic Evaluation: Effects on Probabilities of Success

Although the more sophisticated types of project selection models have not found extensive use, and although the estimates of development cost, development time, and profitability are not very accurate, this does not mean that firms do not find it worthwhile to make relatively straightforward (and often rough-and-ready) evaluations of various project proposals and of continuing projects. On the contrary, the available evidence suggests that most firms make such evaluations--and that a firm's chances of success are related to how quickly such evaluations are carried out.

The probability of technical completion is the probability that an R & D project will achieve its techical objectives. The probability of commercialization (given technical completion) is the probability that a technically complete R & D project will be commercialized--that is, that there will be a full-scale marketing or application of the new or improved product or process beyond a test-market or pilot-plant trial. The probability of economic success (given commercialization) is the probability that a commercialized R & D project will yield a rate of return (on the R & D costs plus any additional investment made to introduce the innovation) in excess of what was available from other (non R & D) investment alternatives. Note that the product of

We would expect that all three of these probabilities would be affected by how quickly R & D projects are evaluated from the point of view of potential market and profit. Some firms allow R & D projects to proceed much farther than do other firms before the potential profitability of the project is studied. Table 1 shows that, on the average, the firms that Wanger and I (1975) studied permitted about $40,000 to be spent on a R & D project before such a study was made. But there was a great deal of interfirm variability in this respect. Some firms allowed $200,000 to be spent before such a study, whereas other firms spent little or nothing before it.

In general, there are many arguments for integrating technological considerations with economic considerations relatively early in the game. Unfortunately, one suspects that many firms do not integrate these factors early enough, the result being that many projects with very little potential economic payoff are started and continued too long. And because this is the case, the probability of technical completion is lowered, since more projects are started which are stopped short of technical completion because of poor profit prospects. Also, the probability of commercialization (given technical completion) is lowered because more projects are completed technically before it is recognized that their profit outlook is poor. And the probability of economic success (given commercialization) is lowered, since the firm's portfolio of R & D projects tends to be more poorly geared to economic realities and conditions than would otherwise to the case.

Based on detailed data for 16 firms, Wagner and I (1975) found that, holding other factors constant, each of these probabilities of success was directly related to how quickly economic studies of this sort were carried out. More specifically, each of these probabilities was inversely related to the amount (in thousands of dollars) that could be spent on an R & D project before studies were made of market and potential profit. This relationship was highly significant.

Conclusions

Considerable advances have been made in recent years in the measurement of social returns from industrial innovation. Studies of such social returns have played an important role in recent policy discussions concerning civilian technology (for example, President Carter's Domestic Policy Review on Industrial Innovation). Much has also been learned in the past decade concerning the ways in which firms evaluate R & D timates of development cost, development time, and profitability are quite inaccurate. For this and other reasons, firms seldom use the more sophisticated models proposed in the literature to select projects. Instead, they generally use simple (and often rough-and-ready) adaptations of capital budgeting techniques. Despite the inaccuracy of the estimates, the available evidence suggests that firms that make a systematic attempt to evaluate a project's economic potential relatively early in the game tend to have a higher probability of success than do other firms.

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LESSONS ON EVALUATION OF RURAL DEVELOPMENT RESEARCH-EXTENSION PROGRAMS BASED ON THE TITLE V EXPERIENCE

J. Patrick Madden*

Introduction

The organizers of this symposium invited me to address the topic of evaluation as related to rural development and/or small farms. I will discuss evaluation of a small but important aspect of the former and disregard the latter. Specifically, I will not discuss the area of small farms. Rather, I will simply refer to a forthcoming report which evaluates the state of past research on small farms and proposes an agenda for future research (Madden, et al, 1980). I will however, discuss the evaluation of a specific type of rural development research-extension program conducted by the land-grant university system, namely, Title V of the Rural Development Act of 1972. Beyond the scope of this paper is the recent USDA evaluation of cooperative research, including community resource development and other kinds of rural development extension efforts (USDA, 1980). Also beyond the range of this essay are evaluations of other kinds of rural development programs, such as capital funding programs to provide water and sewerage systems, roads, etc.

What is Rural Development?

For purposes of the present paper, "Rural Development" will be defined as follows:

> Rural Development encompasses the many dimensions or conditions which determine the quality of life: access to public services and facilities; economic development; protection or enhancement of natural and environmental resources; and the capacity of rural people, communities, and institutions to interact effectively in identifying and attaining goals. Each of these dimensions can be viewed in terms of its present level or state (e.g., availability of health services, median income or employment) and in terms of its trends (e.g., improvement, stagnation, or deterioration of the local economy, services, or environment). Development then, is a normative term implying the attainment of levels and trends desired by people themselves.
>
> Economic Development means "improving" the level, distribution, and stability of earnings and employment. This can be done in a number of ways, such as increasing the productivity and/or efficiency of existing firms and resources. It can also be done by expansion--enlargement of existing firms or entry of new industries. Expansion is not feasible in all rural areas, nor is it everywhere desired or appropriate. In areas experiencing very rapid growth, for example, local residents might feel that an "improved" trend is a reduction in the rate of economic expansion. Therefore, economic development is a goal of a comprehensive rural strategy, but only one of many goals and a goal which must be shaped to local desires. (Cornman and Madden, 1977).

Thus, we see that rural development, broadly conceived, is multidimensional. And we see that the economic dimensions are important but not exclusively important. Unfortunately, many of those in USDA and elsewhere who control budgets for rural development programs tend to view rural development objectives and outcomes rather narrowly in economic dimensions--increases in aggregate income or value added, more equitable distribution of income (reduced incidence of poverty, for example), increased employment, etc. Practitioners at the local and state level, however, often encounter rural community objectives that transcend the economic dimensions--improved roads, housing, water, sewerage, health, and other services; increased competence of local government; protection and improvement of environmental resources, etc. This incongruence between the perceptions of grass-roots people versus federal bureaucrats is a major threat to the continued funding of certain types of rural development activity, and an awesome impediment to realistic and effective evaluation of rural development programs.

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calls on the nation's land-grant universities to help rural people attain their development goals by establishing linkages among research, extension, government agencies, and rural people. Specifically, the Title V program within each state (and Puerto Rico) is expected to accomplish the following purposes:

*provide information and assist in the interpretation and application of information needed by various public and private agencies and decisionmakers involved with achieving the various development objectives or end products--particularly those related to improving public services, employment opportunities and income;

*provide research and investigations useful to those planning, carrying out, managing, or investing in facilities, services, businesses, or other enterprises (both public and private) that may contribute to rural development; and

*enhance the capabilities of various colleges and universities in each state to perform vital public service roles of research and practical application of knowledge in support of rural development.

(Madden et al, 1977)

It was the declared intent of Congress that the land-grant universities should be given three years to operate Title V as a pilot program, with the understanding that if the program appeared successful at the end of that three-year period, it would be expanded substantially with additional funding and would be given more permanent authorization. The national evaluation of Title V was quite positive regarding the contributions and the potential of this program (Madden et al, 1977). In spite of these findings, however, the administration has not supported Title V and each year the Congress has appropriated only minimal funding--$3 million dollars in each of the first three years and $4 million dollars in each of the succeeding years; the currently proposed budget requests no money for Title V. Consequently, Title V has languished.

Evaluation and Policymaking

As a student of public policy for many years, I have observed a fairly consistent pattern, a kind of policymaking treadmill that goes something like this:

The Stages of Liberal Policymaking

Stage I	Recognition of the Great Problem in some fashionable area such as poverty, small farms, or rural development.
	ment. Great fanfare for the brilliance of the program and the policymakers who conjured it up.
Stage III	Program Operation--usually with adequate funding, over too short a time span, and with no plan for useful and credible evaluation.
Stage IV	Growing disenchantment with the Program. Through lack of funds, inadequate time to fully develop the Program and/or because there is no credible evaluation data, the Program lacks evidence of success in solving The Great Problem. It has now been long enough since the fanfare stage that it is fashionable to ignore or to oppose the Program.
Stage V	Program declared a failure.
Stage II (again)	Start again at Stage II and create another New Program to solve The Great Problem, while heaping abuse upon those responsible for carrying out the original Program.
Stage I (again)	Eventually, the Great Problem may go away or sink into oblivion because of declining public visibility and political support. When this happens, the liberal policymaker returns to Stage I, defines a new and currently fashionable Great Problem, and conjurs up a New Program to solve it. Thus, the policymaker never runs out of work to do, and he always gives the impression that he is indispensible--for he is constantly contributing greatly (he contends) to solution of society's Great Problems.

One of the best recent examples of this seemingly endless process is the impending demise of Title V of the Rural Development Act of 1972. In spite of strong evidence that the program could succeed (Madden et al, 1977) it has never enjoyed the support of any administration (Nixon, Ford, or Carter), and it now seems destined to die from lack of funding. Eventually it may reincarnate as a fashionable "new" approach--perhaps as the rural circuit riding manager, cited favorably in the President's recent policy statement on rural development (Carter, 1979). Given the current state of inflation and national economic decline, and of austere federal budgets, it seems highly unlikely programs such as Title V seem destined to fall short of their potential contribution unless constructive and scientifically credible evaluation becomes a standard part of program operation. The type of evaluation needed stands in sharp contrast to the grateful testimonials and post-hoc reviews that currently pass as evaluations.

It seems self evident that evaluation is indispensable to policymaking at all levels--from the level of the legislative committee's action in deciding appropriations and concocting new or revised programs, through executive policymaking in creation of regulations and initiating budget proposals, through local decisionmaking regarding ways to implement existing programs. Obviously, programs that enjoy immense popular and political support can survive and prosper despite a lack of evidence of effectiveness or cost-effectiveness, *e.g.*, food stamps. Other programs may languish in spite of compelling evidence both of need and of performance. Thus, program evaluation is neither necessary nor sufficient for a program's prospering.

Compounding this lack of responsiveness, however, is the fact that many evaluations are so poorly done that they provide no solid basis for policymaking, either of the summative type (program survival) or the formative type (self improvement of the program through feedback of evaluation findings).

Often it seems bureaucrats tend to embrace evaluation studies which reinforce their preconceived notions of the program. Likewise, they tend to ignore or discredit those studies whose findings run contrary to expectations and preconceptions. Thus, one can with some justification assume the cynical view that evaluation of social programs is a waste of time and money.

Apart from such cases of bureaucratic prejudice, however, a more constructive view is that *good* evaluation can become indispensible by proving its capacity to (1) suggest improvements in the way programs are administered, (2) document the program's performance with credible and truthful evidence, (3) enhance the scientific basis for predicting program outcomes under diverse conditions and alternative policy provisos. Herein lies the challenge of evaluative research. It is my belief that ultimately the goals of rural development will be best attained and the public interest best served if all rural development programs are subjected to a systematic and scientific evaluation. Before discussing the anatomy of such an evaluation, we will review the way in which the 1977 evaluation of Title V was conducted, as a basis for comparison

Virtually every program evaluation could be improved upon in retrospect. With the knowledge gained during and after the evaluation study, the evaluator can easily see ways in which all aspects of the study could have been more improved --from the initial conceptualization of the program and its objective through the measurement of program performance, analysis, and reporting of the findings. The Title V evaluation (Madden *et al*, 1977) is a prime example. The following is an excerpt from the final report:

> At the end of the three-year pilot stage, which included fiscal years 1974 to 1976, the U.S. Department of Agriculture authorized and funded the present evaluation of Title V. Given that the expectations of Congress with regard to Title V were predicted on five times greater funding than the states actually received, state program outcomes cannot be unequivocally matched against those expectations. Nonetheless, this evaluation addresses the issue of whether the land grant institutions administering Title V programs in each of the 50 states and Puerto Rico have contributed significantly, given their funding levels, to the process of rural development through their research and extension programs. The study also inquires whether the programs were carried out in conjunction with other institutions of higher learning, in cooperation with the various federal, state, and local governmental agencies and private groups and businesses attempting to effect rural development.

Conceptualizing the Evaluation

There are three levels on which the program may be evaluated: (1) the *federal* level, (2) the *state* program level as developed by the land grant institution, and (3) the individual *project* level within the state program. Additionally, three types of evaluation can be done: (1) *impact* analysis of rural development end products or outcomes (such as increased employment or improved services), (2) analysis of the rural development *processes* or *procedures* initiated and utilized by Title V in attainment of rural development end products, and (3) *formative* evaluation or *feedback* consisting of ways to reformulate or redirect rural development activities.

For each of the three program levels, this evaluation focuses primarily on the process and feedback types of analysis, as consistent with the intent of Title V.

of the end products of the rural development process, the direct intent of the first four titles of the act. However, this study does include state programs' outcomes, as reported by the program leadership personnel. The reason for this choice is as follows.

Even in cases where the state Title V programs are reported to have contributed significantly to the attainment of some rural development end product (such as new jobs, expanded health facilities, improved quality of streams) it is impossible to ascertain whether the improvement is due entirely to Title V, or to some event or activity external to Title V. Before an evaluation can make causal inferences regarding program impact, rigorous evaluation design standards must be met. Such an evaluation utilizes applied social science research methodology to guide the evaluation process. For example, pre- and post-program data are collected from groups which participated in the program (or some variant of the program) and a group which did not participate. This approach permits (under ideal conditions) causal inferences concerning program outcomes. As one moves along the continuum from informal evaluation (lacking systematic data collection and analysis procedures) toward the more scientifically rigorous evaluation research (based upon experimental methodology, statistical inference, etc.), more confidence may be attributed to the causal inference that the program under scrutiny is in fact responsible for the post-program outcomes. This preferred experimental/quasi-experimental approach to impact evaluation permits researchers and policymakers to make the strongest argument that observed outcomes have been a function of the program under study.

That traditional type of impact evaluation, however, is not feasible in this evaluation study, due to the fact we do not have a controlled experiment for the 51 diverse programs. Rather, the Title V pilot period is viewed as a "naturalistic experiment," 1/ in which 51 land grant universities received a specific allocation mandated by the Act and proceeded to develop highly individualized programs within the guidelines and regulations established by USDA. Due to the lack of experimental control, and the survey methodology utilized (which will be discussed below), Title V outcomes reported by the states cannot be causally uted entirely to reported Title V activities. ment, which is clearly impossible in a program of this type.

Therefore, across program levels, rigorous analysis of the Title V impact has not been possible. Nonetheless, the wealth of information reported by state programs can provide tentative and indirect indications of Title V project outcomes and impact. Examples of specific projects and outcomes appear in Part III of this report. Information on every active and completed Title V project is presented in the Directory of State Title V Rural Development Programs.

Other types of evaluation are much more feasible with the available data. Process evaluation focuses on the extent to which a program's operation is consonant with the program as originally designed (in this case, by Congress in the Act and USDA in the regulations). At the national level, for example, this study examines the extent to which Title V stimulated the states to create the kinds of administrative and advisory structures required by the law. Also, at the state level, an extensive analysis of process and procedures utilized by state programs in relation to Congressional expectations has been completed, examining the manner in which the land grant universities created organizational structures and procedures for designing and implementing their Title V programs.

Finally, this study is a formative or feedback evaluation; that is, it provides feedback of results to numerous rural development professionals (including individual state program staff) and policymakers. For example, the evaluation reports desired changes in the legislation and regulations pertaining to Title V. State program level information available for feedback is also abundant. For example, one product of the evaluation is a detailed directory of all 51 programs, with an alphabetical index of types of projects implemented by the states and Puerto Rico. That directory will permit a flow of information between states that is not now possible. For example, when the rural development personnel in one state wish to initiate a rural housing project, they will be able to contact other states which have already implemented this kind of project, and obtain information from that state's project personnel on ways to proceed and problems to avoid.

ferred that the evaluation be conducted externally, a cooperative agreement was made between USDA and the National Rural Center. NRC in turn obtained from the Pennsylvania State University the services of a project director and principal investigator to design and conduct the evaluation under the general direction of NRC. The principal investigator found that the information on file with USDA (Annual Plans of Work and Progress Reports) was largely ideosyncratic, and did not provide systematic information that would be comparable across states. Therefore it was decided, in consultation with USDA, that a survey would be conducted to collect data from all the states and Puerto Rico. Separate, self-administered questionnaires, with some degree of overlap, were developed for state coordinators and program leadership and the analysis was based on the total population of 51 land grant institutions receiving Title V funds. The survey instruments attempted to look at a wide range of variables concerning both program development and program outcomes. As the survey was not conducted until the close of the three year pilot period, the evaluators were unable to collect information prior to and during program development. In addition to questionnaire responses, the evaluation includes analysis of Plans of Work, Progress Reports, and 11 state site visit reports.

The majority of the analysis entailed content coding of open-ended responses and tabulation of closed-ended responses to ascertain national or regional trends. Although the categorization of question responses did not follow systematic content coding procedures (with emphasis on mutually exclusive coding categories, high inter-rater reliability, etc.), the entire analysis has been subject to quality control reviews within the evaluation staff. In some cases (notably the case studies and the data on agency involvement) preliminary drafts were sent to the states for review. This was not done with all the report, because of time limitations.

Ideally, the analysis should have been based on data collected by personal interviews and/or telephone interviews with program personnel in each state. However, because of the limited time and resources available, face-to-face interviews were not feasible; telephone interviews would not have provided an opportunity to solicit the diversity and detail of information and intent of individual questions, respondents also received a User's Guide.

Steps in the Evaluation

As discussed, this evaluation is based upon a naturalistic experiment rather than a more traditional research design. As such, evaluation activities undertaken differ from traditional research activities. This list of steps followed in evaluating Title V should clarify the conduct of this study:

1. Starting in September 1976, Plans of Work and Progress Reports submitted by the states were reviewed.

2. Selected literature on rural development, Title V, and program evaluation was reviewed.

3. A working model of Title V and a series of critical research questions were developed to guide the evaluation.

4. Questionnaires were developed, to be completed by key persons in the Title V operation of each state -- the State Coordinator of Title V (usually the Dean or Vice President of Agriculture) and the program leadership (person(s) in charge of daily Title V operations). This process included a pre-test in which six states (Delaware, Idaho, North Dakota, Pennsylvania, Tennessee, and Texas) participated.

5. Meetings were held in Washington, D.C., with key policymakers from Office of Management and Budget, Congressional Committee staff members and others, to determine whether the evaluation design was omitting any significant issues.

6. A User's Guide, to explain and illustrate questionnaire items, was prepared to accompany the questionnaires mailed to respondents January 15, 1977.

7. In February 1977, meetings were held in the Southern, Northeastern and Western Regions to discuss and explain the questionnaires and evaluation to state personnel involved in Title V. Following the second of these meetings, a questionnaire addendum --reformulating some of the items--was prepared and sent to all respondents. (The questionnaires and addendum are included in Appendix C.)

California, Iowa, Missouri, Wisconsin, Ohio, North Carolina, New Hampshire, Rhode Island, Connecticut, Michigan, and Puerto Rico. The purpose was to discuss the organizational changes made by the institutions of higher learning in meeting the demands of their Title V operations, and to get first-hand information on the various projects within each state's Title V program.

9. By May 1977 nearly all the questionnaires had been returned. Data from the questionnaires, plans of work, progress reports, site visit reports, and various telephone discussions with state Title V personnel were analyzed.

10. A review draft of the evaluation report was prepared on June 15, 1977. This draft was reviewed by the National Rural Center, the director of each of the four regional rural development centers, and other rural development professionals.

11. A second review draft was completed on September 3, 1977.

12. Guided by review comments from previous drafts, additional analysis was done, and the final report was completed.
(Madden, et al, 1977, Ch. 2)

Perceived Deficiences in the Evaluation

As with most self-administered survey instruments, a number of problems arose. Three main problems are evident:

1. In virtually all states, two or more individuals (often representing different rural development perspectives), assisted in responding to the questionnaires. Persons in charge of program leadership usually had substantial input into the state coordinator questionnaire, and other Title V staff usually contributed to the program leader questionnaire. However, there are occasional examples of conflicting data within and between the two questionnaires.

2. Project data forms (such as question 9.4 in the program leader questionnaire--see Appendix C), solicited specific information on state's projects. More specifically, data were sought on (a) description of the project and target area, (b) duration agencies or organizations, (d) involvement of research and extension personnel, (e) organizational changes and tangible outcomes brought about by the project, (f) project beneficiaries, and (g) unique contributions of Title V, despite the diversity of the closed and open-ended questions, it was difficult for the respondents to fully present the complexities and richness of individual projects on the data forms. Site visits have confirmed respondents' observations that the essence of a project frequently is not accurately portrayed by responses to the questionnaire or in other written information.

For example, upon reading the Program Leadership questionnaire from Puerto Rico, the principal investigator formed the impression that the importance and impact of the program has been over-stated. This impression was abruptly reversed during the site visit. After speaking with area residents and seeing the major improvements in running water, housing, sanitation, roads, bridges, and other aspects of life in the area, the analyst realized that the questionnaire data significantly (though unintentially) understated program outcomes. Discrepancies in the opposite direction probably occurred as well.

3. Although both questionnaires were pre-tested and filled out by knowledgeable individuals, they appear to have been too complex for self-administration. The User's Guides for the State Coordinator and Program Leader questionnaires greatly clarified the intent of individual questions, but response ambiguity and incompleteness still suggest that the questionnaires were overly complex for self-administration. The data analysis demonstrates that respondents interpreted questions differently and to a large degree, did not follow general or specific question instructions. These problems have implications regarding the validity and coverage of the data.

Because there is no method currently available to check the intended meaning and accuracy of the responses, the evaluation staff exercised caution in drawing conclusions. Of course, the external evaluation has utilized additional documentation when available, but state questionnaires cannot be validated against original purpose was to learn more about the organization of programs and projects, not to validate questionnaire responses. Anecdotal information obtained from personal contacts with respondents has led to the impression that the data are, in the vast majority of cases, candid and accurate reflections of the Title V programs as perceived by the key personnel who responded to the questionnaires.

Another deficiency of the evaluation design is that it was ostensibly an "in-house" evaluation. The principal investigator (Madden) is an employee of one of the land-grant institutions (Penn State University). Even though none of his salary has come from Title V and despite the fact that his initial orientation toward the program was highly skeptical, the positive findings of the evaluations have been interpreted by some as "biased" because of his institutional affiliation.

In summary, the 1977 evaluation of Title V was a post hoc evaluation of the process and content of each state's program, with no attempt to evaluate objectively the impact of specific projects. Data for the evaluation were obtained through self-administered instruments, supplemented by selected site visits. The evaluation study was intended as a formative exercise in that the reports contained many suggestions for further improvement of rural development activities.

A unique feature of this evaluation study was the contractual provision for creation of a post-evaluation policy statement, plus debriefing meetings with the intended audience at the federal level--various officials in the legislative and executive branches of government having power over the funding and future of Title V.

Contrast With an Ideal Evaluation

What Is an Ideal Evaluation?

Evaluation, like other kinds of publicly supported activity, should be cost effective. That is, the expected gains from the evaluation should exceed the cost of conducting the evaluation.

An ideal evaluation should be, among other things, realistic in relation to the nature and scope of the program being evaluated. For example, one does not realistically call for a $5 example, to require each state to conduct an objective, scientific evaluation of each of the program's several projects. To do so would have negated the true intent of the pilot program, which was to determine whether the land-grant institutions could tool up, as required by the act, and proceed with educational resources of various state institutions of higher learning available to rural communities, citizens, and agencies, thereby helping with the identification and attainment of locally perceived rural development goals. Given the miniscule level of funding most states received (median state allocation $46,672 per year during the first three years) and the realistic uncertainty of year-to-year continuation of the program, imposition of rigorous evaluation procedures for various projects would have been ludicrous.

If and only if the level of funding for Title V is substantially increased (beyond the current $4 million per year), and if the authorization and funding levels are made more permanent, it would make sense to create an evaluation process. Some of the desirable features of such an evaluation process would include documentation of (1) program performance, (2) contextual conditions, (3) program inputs, and (4) processes used in implementing the program. The ideal evaluation research study is, first of all, excellent-quality research. And, finally, the ideal evaluation should end with a policy assessment, including suggestions for improving the program, its regulations and its implementation.

We turn now to a discussion of specific features of an ideal evaluation, as compared with the 1977 Title V evaluation.

Document the Performance of the Program

An obvious role of evaluation is to ascertain how the program performed in the specific context and point in time in which it has been operating. This aspect of evaluation requires, as a minimum, documentation of outcomes with regard to the program's stated objectives. The Title V evaluation did not attempt to verify the outcomes reported by the various state program administrators nor was there any effort to ascertain the impacts of the hundreds of individual projects. This would have required massive resources, plus a concurrent evaluation design rather than the post hoc procedure to which this evaluation was constrained. That is, impact evaluation requires an on-going evaluation study, including collection of appropriate data at various stages at the end of the three year pilot phase of the program, nothing more than a post hoc evaluation was feasible. Records and progress reports submitted annually by the program administrators were available to the evaluators, but these documents were of little value to the study because of the insufficiency of the information they contained. The questionnaires used to collect data for the evaluation were, by their nature, retrospective instruments asking for post hoc recall of details of the state's Title V program design and its various component projects. The only exception was Missouri, where the program administrator (Hobbs) hired a person to conduct an on-going evaluation of the Title V activities. (Madden et al., 1977, pp. 245-262)

In retrospect, the Title V evaluation should have included more in-depth site visits, such as those conducted in Missouri, Puerto Rico, and California. Furthermore, the site visits should be repeated at two or more points in time (Hagood, 1979, Appendix C). Such a longitudinal design was unfeasible given the short span of time allowed for the evaluation. However, subsequent revisits have revealed much valuable information that would have significantly increased the realism and specificity of the evaluation findings.

Document the Contextual Conditions and Inputs

A proper evaluation should include thorough documentation of the various factors that contributed to (or impaired) the performance of the program and its component projects. These factors include the levels and qualities of various inputs (program staff, funding, operational resources provided by participating institutions). Also essential is documentation of the "relevant" contextual features, such as demographic, economic, topographic, and other characteristics of the locations in which projects were conducted. What is "relevant" information in evaluating a specific project depends on the theoretical model of causation underlying the evaluator's conceptualization of each project--how does it operate, what are the necessary ingredients, what barriers must be surmounted, what factors influence the project's performance? Similar causal modeling underlies evaluation of an overall state program.

Document the Processes Used in Implementing the Program

Organizational and administrative features, such as research-extension cooperation and interdisciplinary linkages, are fundamental to success of Title V programs. Likewise, the level of institutional in-kind support for the program is a critical variable that should be documented.

became clear that the evaluation had failed to obtain some essential data--the level of in-kind support by the land-grant universities. Upon careful examination of state budgets and plans of work, it became abundantly clear that those documents did not contain the basis for estimating the value of in-kind contributions--overhead, fringe benefits, salaries of key professional personnel, and other essential data were typically not reported. Understandably, the inability to estimate the value of state in-kind contributions to Title V was considered by some OMB officials to be a serious defect in the evaluation. In retrospect, the criticism is, of course, well taken. Unfortunately, none of the intended audience or other reviewers raised the question of in-kind contributions during the early stages of the study. Consequently, this factor was omitted from the evaluation data, an oversight for which I take full responsibility.

In view of the importance of organizational and administrative features, the evaluation questionnaires were designed to determine all the "relevant" aspects. Again, the underlying theoretical model dictated what features were "relevant." In retrospect, more attention should have been given to identifying and documenting aspects of the rewards system which influence faculty members' decisions whether or not to participate in rural development research and/or extension activities. Even more important, it seems now, are faculty perceptions of the reward systems--their beliefs regarding the impact their Title V roles may have on their tenure, promotion, or pay increases. The weak and uncertain funding for Title V undoubtedly plays an important role in many states in shaping faculty perceptions of the professional rewards (or penalties) they might ultimately receive via Title V program activity. Since a professionally rewarding research program typically requires several years to develop, the likelihood of premature termination of Title V fundings has undoubtedly discouraged many researchers.

Another very important deterrent is the belief expressed by several faculty members that Title V research does not lead as readily as other types of research to reports or articles acceptable to professionally refereed journals. And since a researcher's tenure, promotion, and sometimes salary increments are determined, at least in part, on the basis of his/her rate of publication in refereed journals, this perception may act as a strong deterrent to research involvement in Title V activity. About one-third of the states reported that the university rewards system was, to some degree, incompatible as more professionally rewarding than the developmental research keyed to solution of immediate practical problems, often requiring quick completion using procedures thought to be routine and unattractive to professional research journals (Madden et al., 1977, p. 75).

Evaluation as Research

Evaluation, in the ideal sense, should be impeccible research. It should start with theory, in the sense that the conceptualization of the study, measurement of variables, and analysis plans should be based on the current state of theory underlying the program or project being evaluated. It should end with theory, in that the findings of the evaluation should be integrated into the body of knowledge, providing an improved basis for predicting program performance, under an expanded range of conditions and program options.

The 1977 Title V evaluation falls far short of the ideal in regard to forming linkages with existing thoery and modification of theoretical paradigms. The evaluation was essentially decriptive in nature. As such, it provided valuable base-line data for possible future evaluation studies, but it did little to advance the science of rural development.

Creation of a Post-Evaluation Policy Statement

A unique feature of the 1977 Title V evaluation was that, by design, it included the development of a policy statement following completion of the formal evaluation report. This statement (Cornman and Madden, 1977) examined the major provisions of the act, and suggested ways to modify the legislation so as to ensure greater effectiveness in the future. While some have been critical of certain recommendations (for example, opening the program leadership to universitites other than the land-grant institutions), the concept of calling for the creation of a policy statement as part of the evaluation contract seems to have considerable merit and should, in my opinion, become standard procedure for major evaluation studies.

The Bottom Line

Several lessons occurred during and after the 1977 evaluation of Title V, lessons that hopefully will be useful to those conducting future studies of a similar nature:

1. Avoid post hoc evaluations. While this lesson is not unique to the Title V evaluation, nor was it new to this evaluator, it was once again reaffirmed with such force during this study that it bears repeating here.
2. Conduct as many in-depth site visits as possible. The example of Puerto Rico, cited previously, illustrates the need for site visits to [illegible] the evaluator begins seeing more in the data than other analysts (without the benefit of the same site visits) can see. Hence, the scientific requirement of repeatibility tends to become impractical. Furthermore, the written word or data cannot adequately portray the essential qualities often observed during site visits. And while this may increase the frustration level of the evaluator at times, it is an essential part of a good evaluation.
3. Beware of changes in expectations of the target audience. It makes sense to ask responsible persons among the intended audience to react to the evaluation design and to suggest changes during the early stages of the evaluation--while there is still time to add, modify, or delete items from the data collection procedure. And while this commendable attribute was built into the design of the Title V evaluation, subsequent changes in federal personnel seriously undermined these efforts, for the new bureaucrats had different expectations and views of Title V than did their predecessors. One key official recently stated flatly the hope that Title V would soon expire. Upon probing, this official revealed (1) expectations for Title V which are clearly contrary to both the law and its legislative history, and (2) a total lack of sympathy for the purposes for which Title V was intended. Under these circumstances, the design and content of an evaluation are sure to be considered inappropriate --unless the findings support the prejudices of the official.
4. Don't become discouraged by biased perceptions of the study's findings. Maintain high standards of intellectual integrity and, to the extent possible, scientific objectivity while pursuing the art and science of program evaluation. False and naive expectations regarding the objectivity of key officials controlling the program's future can lead only to despair. Be not dependent upon a favorable reception of the study by public officials as your primary source of motivation. Rather, enjoy the study for its own sake, as a craftsman enjoys a job well done.

Footnotes

1/The distinction between a naturalistic experiment and the more widely known "controlled" experiment is as follows. In a controlled experiment, rigorously defined treatments are systematically applied to predetermined subjects or groups with a control group receiving no treatment at all. In a naturalistic experiment, the subjects are permitted to determine their own course of behavior, within broad guidelines established by the nature of the program, and no control group is used. In analyzing the outcomes of a naturalistic experiment, attention is directed not only toward the results achieved, but also toward the processes and methods of organization selected by the participating subjects.

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TECHNOLOGY ASSESSMENT AND THE NATIONAL MODEL

Klaus Alt, Earl Heady, and Burton English*

We present possibilities for generating economic intelligence by use of a national model to aid in the assessment of technological changes and research returns. At the outset, we want to differentiate two types of technology assessment: *ex post* and *ex ante*. The *ex post* assessment measures what has happened in the past; a national programming model is not an efficient tool to measure this type of change. The *ex ante* assessment suggests which types of technological change could occur in the future and/or which types of change should occur to satisfy future demands. It is the latter assessment for which a national programming model is uniquely qualified. We will restrict this paper only to the *ex ante* assessment.

The objective of this type of analysis is to generate information on the possible impacts of technology changes. There are several alternative ways of meeting this global objective. One can look at technology changes which are either presently underway or imminent and assess their impacts on methods and location of agricultural production, levels of output, resource returns, shadow prices, consumer and producer surpluses, and other target variables. Alternatively, one can use such a model to identify the priority areas for research and extension, either on a regional, crop, or production process basis. Finally, one could "solve the equation backwards" by specifying future demand levels and solving for the technology changes required to meet those levels.

The traditional studies estimating returns to research are on an aggregative basis for all of agriculture, although there are a few for individual commodities such as poultry and hybrid corn. The aggregate estimates tell nothing about where the marginal returns from research expenditures are greatest. Neither do they tell us whether marginal returns from research investments are constant, increasing or decreasing. Also, those which estimate returns for an individual commodity do not allow us to make comparisons of marginal research returns for other commodities.

Our programming models could be used for such purposes. We could go to the extreme and use linked linear programming - recursive simulation models to trace out these possibilities over time. We could use a quadratic separable programming model to estimate these details at a point in time. Or, we could use a simpler linear programming model for this purpose. We suppose that such a model incorporates a sufficient number of regions to express regional differentials in climate, natural resources and income conditions of agriculture.

Agricultural scientists could (1) list each possible new innovation in agriculture which is known and/or (2) list each potential innovation possible. Even for the latter case, they also could quantify estimated yield effects and required inputs. (Scientists should do this anyway as they go about their research, as a manner of giving it intellectual ordering.) Then these estimates of yield effects and input requirements can be incorporated in the model. The results of each innovation, by crop, cropping practice, and region, could then be traced. Under this detail, the marginal return of each practice, or of practices in combination, could be estimated in terms of either (1) resources saved to attain given demand levels, (2) producers' and consumers' surplus, (3) income increases or declines to agriculture, (4) the distribution of these economic impacts by land class, by producing area, or by agricultural commodity, (5) the shifts in production by crops and regions, (6) changes in supply prices of crops--nationally or by regions, (7) etc.

There are many alternative national program-

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plex. On the aggregate end of the spectrum, one can find demand-and-supply-function models for a single commodity with no regional detail. On the complex end, one finds multi-region models with many commodities and thousands or tens of thousands of alternative production processes. We are involved in the latter type of programming models. Some of these programming models are linked recursively with econometric simulation programming models so that endogenously determined prices are fed back to determined output and resource use--which again impact through the model on prices. Other models incorporate demand functions and in quadratic form determine prices, production, and resource use endogenously. They have been used on a separable basis to estimate consumer and producer surplus from various types of change in agriculture.

There is not time (nor reason) to explain in detail the features and capabilities of the several ISU models; each has its own merits, drawbacks, and peculiarities. For the purpose of this discussion, it suffices to describe these models as having many production regions (most models have 105 producing regions to cover the 48 contiguous states) and a large number (now about 40,000) of crop production possibilities, differentiated by 330 crop rotations, four tillage methods, three soil conservation methods, and five land classes. This massive amount of detail makes it feasible to use these models to generate information on, for example, the regional change in crop production levels and methods induced by a certain type of technological change in a comparative static analysis.1/

We will describe some of these possibilities in a bit more detail. A first type of analysis deals with the effects of technological change which increases the yield of specific crops. This yield increase may occur at differential rates in different regions of the country. It is then a relatively simple task to change the crop yields in the model and solve for the new regional distribution of crop production. Intuitively, we would expect to find a relative concentration of this crop in those regions of highest yield increase; a national model of sufficient regional detail will show such a result as a comparison of "before" and "after" runs.

A second type of analysis deals with technological change which is cost changing, either cost-decreasing or increasing. Again, it is relatively simple to adjust the crop production costs in the model, solve the revised model, and compare the results to a base model solution to identify the changes induced by the technological change.

The third type of analysis is probably the most common, namely a technological change which changes yields, costs, and other production input to identify the induced changes. Despite its apparent simplicity, this method is very powerful. It allows us to point out potential regional shifts of production; it can indicate whether an economically marginal region may drop out of production or whether it will gain by the technological change. This method allows us to identify shifts in crop production that might be missed by other analysis methods.2/

Each of the previous types of analysis is based on what might be called a "limited" kind of technological change, either changing yields, costs, or both. There are broader types of technological change which may change basic crop production processes, introduce totally new crops, or some other major change. Can a national model handle those changes also? Certainly it can, with the proper data and skillful programming.

A change in technical crop production processes may be induced by outside pressure, as, for example, a ban on specific tillage practices imposed by environmental legislation. Alternatively, such a change may come from economic pressures, such as a reduction in tillage operations induced by higher energy costs. In either case, a national model can determine the end results of such a change if enough production alternatives are specified in the model. Clearly, this method may require us to specify budgets for production processes which are not presently used or which are only experimental. It becomes a challenging task in itself for the researcher to determine these relevant alternatives and to generate the model budgets. If the researcher is successful in this specification,3/ the model will point out some directions of change and the magnitude of changes on a regional and national level.

The same argument applies for other major technological changes, such as introductions of new crops. Again it is up to the researcher to exercise his expertise in developing the production budgets to include in the model. But note that a national model is a uniquely well qualified method to trace through the regional and national impacts of such potential technological changes.

One can use a national model to help determine priority for research and extension expenditures. This method would use a series of "what if" model runs to solve for the effects of several alternative R & E expenditure targets. A comparison of the results of the several model runs against the decisionmaker's list of priorities should help him/her to choose the most desireable policy, or the research and development investment which gives the greatest return. This use of the national model as a decisionmaking tool has in the past perhaps not received the attention it deserves.

We mentioned a final type of analysis in the introduction, namely to solve from the desired future output levels backwards to the required rates of technological change. In one sense this is the most difficult analysis, because even if we know the future goal, there may be a large number of alternative means to achieve that goal. In this analysis, a national model also can serve a useful function as a decisionmaking tool, because it allows us to estimate the regional and national effects of alternative paths of technological change.

In summary, we have suggested several alternative methods of using national programming models to generate intelligence on the assessment of technological change. Such programming models can be a useful tool in the research or decisionmaking process. They can show expected returns from alternative research investments in different crops or livestock, in different management practices, in different land classes, and in different regions. Thus, they could provide a fairly detailed analysis of the expected marginal return from research in different commodities, regions, etc. However, they also can have importance in indicating which regions, crop groups, and farmers may gain or lose from particular innovations.

Footnotes

1/Full details and documentations on the several ISU models have been published. The publications also include many research reports with national results and regional implications under a variety of assumptions, time horizons, level of detail, and other variables. A full list of completed reports and information on models in progress are available from the authors.

2/ISU models had forecast an increase in soybeans in the Southeast long before that became an acceptable prognosis.

3/If he is not successful, he will succumb to the GIGO syndrome (Garbage In-Garbage Out).

A METHODOLOGY FOR MEASURING POTENTIAL BENEFITS FROM DROUGHT-ORIENTED RESEARCH IN NEBRASKA

Arlen Leholm, Raymond J. Supalla and Glen Vollmar*

Introduction

The growth in agricultural productivity and the significance of science and technology in contributing to this growth has been well documented by Bredahl, Cline, Evenson (1967), Griliches (1964), and Peterson. The results of these studies generally indicate that over the past several decades, investment in agricultural research has paid off with relatively high rates of return. Most of this previous work, however, has been directed at estimating returns to aggregate agricultural research in an *ex post* sense at the national level and does not address the question of potential future returns to research at a state or regional level (Norton). Thus, a particular need exists to develop a methodology for evaluating the potential returns to specific types of agricultural research at a subnational level.

The allocation of agricultural research funds in the United States is determined in large part by political decisionmakers and research administrators at the state level. Although aggregated, national-level, *ex post* estimates of returns to research are useful to state-level research administrators as indicators of research potential and as a means of justifying funding requests, they are not directly applicable to the larger issues involved. A state-level assessment of the effects of agricultural research should be as situation specific as possible, considering at least the geographic distribution of benefits and the division of benefits between consumers and producers. Essentially, research administrators need to know which types of agricultural research can be expected to have the highest payoffs and to whom the gains will accrue.

Answers to questions regarding the magnitude and distribution of agricultural research benefits depend on five primary factors: (1) the impact which a research finding has on production possibilities, (2) the rate and extent of adoption, (3) supply elasticities of the commodities affected, (4) price elasticities of demand for the commodities affected, and (5) agricultural policy. An analysis of potential returns to agricultural research at the state level must consider each of these factors. The purpose of this paper is to present a general conceptual framework for such analyses and also to describe how this framework is being applied in a study of potential returns to research in Nebraska.

Conceptual Framework

The genesis of an agriculturally related technological development occurs in either the publicly supported agricultural research establishment or in the private sector. A technological development influences the production possibilities of agricultural commodities in two major ways: (1) an output-increasing effect or (2) a cost-reducing effect.

An example of an output-increasing technology is an improved crop variety; a cost-reducing technology may involve a change in cultural practices, such as minimum tillage. Generally, a change in technology which results in the same output per acre from fewer inputs is said to be cost-reducing. Similarly, a change in technology which shifts an isoquant to a higher output level with the same level of inputs is considered output-increasing. In reality, most technological changes embody both output-increasing and cost-reducing effects. Finally, both types of technological advances will influence the cost of production and therefore the production possibilities of the agricultural commodities influenced by the technological development.

Once a new technology has been developed, at what rate, to what extent and by whom will it be adopted? How will producers react, assuming an objective of profit maximization? New knowledge generated by private or public research must be

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diffusion of a new technology depends to a large extent on profitability, degree of uncertainty and capital requirements (Lu). Profitability is the most important determinant of the rate of diffusion. Griliches, in his seminal work, indicated that hybrid corn was adopted more rapidly in areas where it was most profitable (Griliches, 1958). In general, it appears that the most rapidly and most extensively adopted innovations are those which are highly profitable, have a relatively certain impact, and require relatively small capital expenditures.

Assuming that a new technological development is profitable for farmers to undertake, how will farmers adjust their crop production patterns? The new technology will lower the cost of production. This will stimulate the early adopter of the new technology to adjust his farming practices. In the early stages of adoption of the new technology, the early adopter will capture some excess profits because his increased production will not have a major effect on commodity prices. Eventually, other producers may adopt the new technology which will cause declines in commodity price, ceteris paribus. The magnitude of these commodity prices declines will depend in part on whether the new technology is global or site specific in nature. Thus, understanding diffusion of technology is crucial to determining its impact at the farm, state or national level (Heady).

If a state's production of a particular agricultural product is small compared to the national or world output, state-specific agricultural research may lower production costs and/or increase state output relative to national output, and only slightly lower the output price (Huffman). The implication here is that a state's farmers should demand state-specific final research products that improve their comparative advantage relative to farmers in other areas. The benefits accrue to them largely as producer's surplus and to the owners of inputs that are very inelastic in supply such as land or water, other things equal (Evenson 1979).

At the national or international level, consumers are the primary beneficiaries of agricultural research, providing agricultural policy doesn't limit price declines resulting from technological change. The price elasticity of demand in the policy-independent case is so low at the national level that the long-term primary impact of agricultural research is to lower the price of agricultural products and to benefit consumers.

Consideration of the factors which influence returns to research makes it evident that an analytical framework for assessing potential re-sumer surplus). It follows, that, in order to estimate these factors, one must know the before and after supply function for all affected commodities and also the prevailing demand relationships. Supply function estimates essentially incorporate all of the production response aspects of technological change, while demand functions are necessary to assess the resulting price responses and corresponding distribution of benefits between producer and consumer.

Estimates of potential returns to specific state-level research programs require that one consider which commodity supply functions will be affected both within and outside the state and how these effects interact with prevailing commodity demands to produce a given magnitude and distribution of research benefits. A hypothetical case example is presented below for purposes of illustrating these interactions and also as a means of demonstrating the relevance of selected key parameters. This case example can also be viewed as a generalized model for assessing potential returns to state level agricultural research.

A Generalized Case

Assume for simplicity that the relevant portion of the United States agricultural economy can be described as consisting of two producing regions, a given state and "other U.S.", each with two enterprise options, X and Y. Further assume that regional supply and total United States demand functions have been defined for each commodity and can be written as:

$$QS^o_{xs} = 400P_x - 800$$

$$QS^o_{xo} = 4000P_x - 8000$$

$$QD_{xt} = 13{,}200 - 1650P_x$$

$$QS^o_{ys} = 125P_y - 500$$

$$QS^o_{yo} = 2500P_y - 10{,}000$$

$$QD_{yt} = 15{,}000 - 1000P_y$$

where:

QS^o_{xs} = quantity of X supplied in region S (state), before technological change,

P_x = price of X,

QS^o_{xo} = quantity of X supplied in region O (other U.S.) before technological change,

QD_{xt} = quantity of X demanded, total U.S.,

QS^o_{ys} = quantity of Y supplied in region S before technological change,

P_y = price of Y,

QD_{yt} = quantity demanded of Y, total U.S.

These equations provide a basis for computing initial (before technological change) producer and consumer surpluses.

Producer surpluses for the two regions can be computed by horizontally summing the regional supply functions to determine aggregate supply for each commodity, setting it equal to quantity demanded to determine an equilibrium and then computing producer surplus as the area above the supply curve at the equilibrium price. For our illustration, aggregate supply for the two commodities is:

$$QS^{o}_{xt} = QS^{o}_{xs} + QS^{o}_{xo} = 4400P_x - 8800 \text{ and}$$

$$QS^{o}_{yt} = QS^{o}_{ys} + QS^{o}_{yo} = 2625\ P_y - 10{,}500$$

Setting $QD_t = QS^{o}_t$ to determine an initial equilibrium price for each commodity yields $P_x = \$3.64$ and $P_y = \$7.03$. At these prices, $QS^{o}_{xs} = 656$ and $QS^{o}_{ys} = 379$. Thus, initial producer surplus for region S is $1,112 per production period, consisting of $538 for commodity X and $574 for commodity Y. The corresponding producer surplus for region O is $16,855, consisting of $5,379 for X and $11,476 for Y (Table 1).

Initial consumer surplus consists of the area under the demand at the equilibrium prices and is thus $47,428 with $15,731 from commodity X and $31,697 from commodity Y.

The next and most difficult step in an analysis of potential returns to research consists of determining what impact a research program might have on farm level production possibilities, how farmers will respond to this change, and thus how the commodity supply function will shift. Different types of research will, of course, have quite different impacts.

For purposes of illustration, assume a commodity-specific technological change which applies only to commodity X. Assume further that the change shifts the supply function to the right by a substantial amount in region X (state) and by a lesser amount in region O (other U.S.).

This illustrative supply shift could be brought about by either a reduction in per-unit cost with no change in output per unit of land (cost-reducing) or through a corresponding equivalent increase in yield per acre (output-increasing). Thus, a modified supply function for X in regions S and O can be depicted as follows:

$$QS'_{xo} = 4000P_x - 7000$$

Where:

QS'_{xs} = quantity of X supplied in region S after technological change, and

QS'_{xo} = quantity of X supplied in region O after technological change.

Note that for both regions the supply functions have been shifted parallel and to the right depicting a constant per-unit change in cost at each output level. The assumed cost decrease per unit of production was assumed to be $.50 in region S and $.25 in region O. This reflects limited transferability of the assumed state level research.

Although a given technological change may be directly applicable to only a single commodity, supply functions for other enterprise options may also change. An increase in the production of product X brought about by a technological change may increase or decrease the production of alternative enterprises depending on how production possibilities and relative prices are affected. This is an extremely important effect to consider, because it may be this phenomenon which accounts for much of the net change in producer surplus.

This "induced impact" of commodity-specific research occurs in agriculture because of the significance of land as the limiting input. Agricultural producers are essentially landholders who allocate limited land to alternative enterprises and for this reason one cannot limit a producer surplus assessment to only one commodity. If the relevant set of producers is involved in producing commodities other than the one directly affected by a technological change, then the indirect effects of the technological change on these other commodities must also be considered as part of total producer surplus. In agriculture, one can handle these interdependent effects by considering acreage and yield shifts across all relevant commodities.

In effect, the aggregate linear programming (L.P.) algorithm, so often used in economic analysis, operates in a similar fashion as the above assumptions. A change in the production function of a given enterprise will influence that enterprise directly as well as the other enterprise activities in the L.P. model.

Assume for purposes of illustration that one knows the new supply functions for the directly affected enterprise (product X in our example) and that one also knows what effect the change has had on per-acre yields. By further assuming

Table 1. Producer and Consumer Surplus Estimates For a Generalized Case Example

Affected Parties	Before Technology Change	After Output-Increasing Technology Change	Difference	Percentage Change	After Cost-Reducing Technology Change	Difference	Percenta Change
	----------------------------Dollars Per Production Period----------------------------						
Producer's Surplus							
Region S							
Product X	538	753	+215	+39.96	753	+215	+39.96
Product Y	574	693	+119	+20.73	410	-164	-28.57
Total	1,112	1,446	+334	+30.04	1,163	+51	+4.59
Region O							
Product X	5,379	5,712	+333	+6.19	5,712	+333	+6.19
Product Y	11,476	11,795	+319	+2.78	11,183	-293	- 2.55
Total	16,855	17,507	+652	+3.87	16,895	+40	+0.24
Total All Producers	17,967	18,953	+986	+5.49	18,058	+91	+0.51
Consumers							
Product X	15,731	17,182	+1,451	+9.22	17,182	+1,451	+9.22
Product Y	31,697	32,805	+1,108	+3.50	30,420	-1,277	- 4.03
Total	47,428	49,987	+2,559	+5.40	47,602	+174	+.37
Total Producer and Consumer Surplus	65,395	68,940	+3,545	+5.42	65,660	+265	+0.41

what the new supply function for Y would have to be in each region in order to maintain constant total acreage. This means that the after change supply functions for Y in each region will depend on how much of the given shift in supply of X occurs because of lower input costs (cost-reducing) and how much occurs because of increased production per unit of land (output-increasing). In order to assess the significance of output-increasing versus cost-reducing technological change, the following illustration considers the two extreme cases, i.e., where the entire shift in the supply of X is due to cost-reducing and output-increasing technology, respectively. For the case where the supply shift for X was assumed to be the result of an output-increasing technology, the following supply functions for commodity Y were computed for regions S and O:

$$QS'_{ys} = 125P_y - 446.5$$

$$QS'_{yo} = 2500P_y - 9{,}566$$

These supply functions assume that the output-increasing technological change caused the average yield of X per unit of land to change from 10 to 13.33 in region S and from 10 to 10.53 in region O. They further assume that the average yields of Y per unit of land were 5 and 6 for regions S and O, respectively, both before and after the technological change which affected product X (see Appendix for computational detail).

For the case where an equivalent supply shift for X was assumed to be the result of a cost-reducing technology, the yields per unit of land were held constant for both commodities. In this instance, the new regional supply function for product Y becomes:

$$QS'_{ys} = 125P_y - 580$$

$$QS'_{yo} = 2500P_y - 10{,}520$$

At this point, the information base is complete for estimating the change in producer and consumer surpluses associated with both a cost-reducing or output-increasing technological change. Given the above supply functions, the new equilibrium prices are $P_x = \$3.44$ for both types of technological changes, $P_y = \$6.90$ for the output-increasing case, and $P_y = \$7.20$ for the cost-reducing case. At these price levels, the new total producer surplus is $18,953 for the output-increasing case, consisting of $1,446 in region S and $17,507 in region O. This means that the technological change induced a 30.04% increase in producer surplus for region S and 3.87% increase for region O. In contrast, the cost-reducing case caused only a 4.59% increase in producer surplus for region S and a 0.24% increase for region O (Table 1). all regions gain substantially more from the output-increasing technological change than they do from the "equivalent" cost-reducing change. Although the cost-reducing and output-increasing effects are clearly the same when only commodity X is considered, they are considerably different when the impact on enterprise Y is also included. This phenomenon occurs because the output-increasing technology causes a shift of the limited land resource to the production of commodity Y.

A Proposed Application of the Above Framework

The theoretical discussion outlined above serves as the framework for development of empirical estimates of the influence new technologies may have on Nebraska farm incomes (producer surplus). The initial step in the empirical framework involves an estimate of the potential input/output changes resulting from a new technology.

A number of approaches could be used to measure input/output changes resulting from a change in technology. Expert judgment of physical scientists could be employed to measure this component. Another approach could involve a historical review of the influence of past technological developments and draw inferences from this toward potential new technologies. Still another approach may involve an econometric analysis of input/output changes over time for crop or livestock activities.

The procedure for estimating potential input/output changes in the proposed study will involve a combination of an econometric approach and expert professional judgment. The case example is for development of a drought-tolerant technology for Nebraska's principal crops.

Farmer Response to a Change in Technology

Once an estimate has been made of a new technology's effect on input/output relationships, then the next step in the empirical estimating procedure is to measure farmer response to the new technology. What factors influence the likely response from Nebraska farmers resulting from development of a drought-tolerant technology? Several key factors include the relative profitability of the farm enterprises affected by the new technology, the degree of uncertainty associated with its adoption, and the capital requirements that are required for its adoption.

An aggregate linear programming model of each of the five study regions in Nebraska will be developed to determine farmers' supply response to the new technologies. This model will have an objective function of maximizing returns to

Nebraska (corn, grain sorghum, soybeans, wheat, and alfalfa) will be included in the model at four levels: a fully irrigated level, two partial irrigation levels, and a dryland level.

The adoption of a new technology may be sensitive to the varying costs of production reflected in the four crop irrigation levels as well as the physical, agronomic, and managerial constraints imposed on the model. The new technology itself may have differential cost of production effects on each of the four crop irrigation levels within the same crop, as well as among competing crop enterprises.

The purpose of the L.P. model, then, is to provide state supply functions for each crop activity, to generate estimates of the relative profitability of the new technology, and to illustrate the associated crop pattern shifts. However, the speed at which the technology will be adapted and the degree of spillover to other states are crucial parameters which must also be estimated in an empirical analysis and will influence the effect of the new technology on farm incomes.

The Price Response

The supply-price response that occurs as a result of the new technology will be a function of the "spillover" of the technology to other areas, the speed of adoption, and the price elasticity of demand for the commodity. The assessment of the spillover effects from any assumed technology change will involve the professional judgment of physical scientists and a review of the historical effects from similar innovations.

Once an assessment has been made of the spillover effects, the respective commodity price responses can be estimated. The study will use USDA's long-term National-International Agricultural Forecasting Model (NIRAP) to determine the price effects resulting from the implementation of the new technology.

The NIRAP model will provide a most likely scenario of commodity prices over time. The state supply response plus the spillover response from other regions will be summed. Then a supply shifter will be imposed on the "most likely" NIRAP scenario to account for the technology's supply-price response.

In effect, the statewide five-region aggregate L.P. will provide the Nebraska supply function estimates before and after a new technology has been implemented; while NIRAP will provide an estimate of the demand and the aggregate

price changes associated with the new technology can be determined from the shadow prices of the L.P. model. An analysis with and without the new technology will provide the farm income effects (producer surplus) resulting from development and adoption of the new technology.

The adoption rate of the drought-tolerant technology will have an influence on farm income. In the early stages of adoption, the early adopter may capture some excess profits because the initial production increases will have a minimal impact on commodity prices or on any aggregate changes in cropping patterns. The technology's adoption rate will be incorporated into the linear program algorithm through a series of iterations to capture the commodity price and cropping pattern adjustments that are likely to occur through time. Adoptive rates will be posited based on profitability, uncertainty, and capital requirements. Additionally, the stream of benefits over time resulting from the drought-tolerant technology will be discounted to a single present value.

Summary

This paper has sought to develop a methodological framework for analyzing _ex ante_ farm income effects of potential new technologies at a subnational level. The framework will be applied to a case example for development of a drought-tolerant technology for Nebraska's principal crop commodities. While the drought-tolerant technology provides a case example, the methodological framework could be applied to a broader range of technological developments. The drought-tolerant technology was chosen as a case example because of available time series data that aided in estimating potential input/output changes in Nebraska's crop commodities and because the spillover effects to other regions which are difficult to estimate were thought to be minimal.

The _ex ante_ methodology outlined in this paper has some limitations. Estimates of farmer response and commodity price changes resulting from a new technology have large elements of subjective judgment inherent in them. While this may limit the accuracy of our analysis, the "what if" approach followed in this study in analyzing the farm income effects of potential new technologies should prove useful to research administrators in determining the payoff of new technologies and to whom those gains will accrue.

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Computation of Supply Function Changes

The supply function adjustments for commodity Y assume a parallel shift and thus an intercept change. This change was computed by solving the following three equations simultaneously:

$$\frac{125Py - I'_{ys}}{Y_{ys}} + \frac{QS'_{xs}}{Y'_{xs}} = A_{ts} \qquad \text{Equation 1}$$

$$\frac{2500P_y - I'_{yo}}{Y_{yo}} + \frac{QS'_{xo}}{Y'_{xo}} = A_{tu} \qquad \text{Equation 2}$$

$$3625P_y - I'_{ys} - I'_{yo} = 15{,}000 \qquad \text{Equation 3}$$

Where: Y_{ys} = yield per acre of y in region S, assumed to be 5 units.

Y_{yo} = yield per acre of y in region o, assumed to be 6 units.

Y'_{xs} = yield per acre of x in region S after technological change; assumed to be the initial 10 units for the cost reducing case and computed at 13.33 units for the output increasing case (the amount which is equivalent to the assumed 50¢ per unit cost reduction).

Y'_{xo} = yield per acre of X in region O after technological change; assumed to be the initial 10 units for the cost reducing case and computed at 10.53 units for the output increasing case and the amount which is equivalent to the assumed 25¢ per unit cost reduction.

A_{ts} = total acres in region S, computed at 141 acres based on the assumed yield and the initial equilibrium production levels.

A_{to} = total acres in region O, computed at 1,923 acres based on the assumed yields and the initial equilibrium production levels.

QS'_{xs} = equilibrium quantity of X supplied by region S after the technological change, computed at 776 units (see text).

QS'_{xo} = equilibrium quantity of X supplied by region O after the technolo-

P_y = price of Y.

I'_{ys} = intercept term of supply function for Y in region S after technological change.

I'_{yo} = intercept term of supply function for Y in region O after technological change.

The above three equations, when solved simultaneously, insure that the total land base for both the regions is accounted for (Equations 1 and 2) and that the quantity demanded of Y is equal to quantity supplied (Equation 3).

When solved for the cost reducing case, one establishes: I'_{ys} = 580, I'_{yo} = 10,520 and P_y = \$7.20. For the output increasing case the solution is I'_{ys} = 446.5, I'_{yo} = 9,566 and P_y = \$6.90.

EX ANTE EVALUATION OF THE SEPARATE EFFECTS OF RESEARCH AND EXTENSION[1]

Yao-Chi Lu*

Introduction

Much research work has been conducted in recent years to evaluate the effects of research and extension.[2] Some of these efforts were conducted at the national aggregate level, while others were conducted at the regional or community levels. The methodologies used in those studies varied, but most of the studies were based on regression analysis of *ex post* data.

There are several difficulties associated with the above *ex post* analyses. First, the time lags from the time of research resource commitment to production of extendable technology (invention), *i.e.*, the leadtime, ranges from a few years to decades. It is difficult to collect time series data to accommodate a long leadtime. Besides, the average leadtime is not known unless one studies specific research projects. Thus, most, if not all, researchers ignore the leadtime. They just assume that research output will come about as soon as the research resources are committed, even though most researchers recognize and account for adoption lag.

Secondly, research and extension enter into the process of technological innovation at different points in time. Although feedbacks from extension often result in changes in the direction or additional research to be conducted, extension plays little role in the development of a new technology. When the research is completed and a new technology is produced, extension comes into play. Thus, extension follows research in that process. Many researchers recognize this lag, but unless dealing with a specific technology, the lag length is usually unknown.

Thirdly, in time series data, research and extension expenditures are highly collinear. One reason for the existence of this collinearity is that the budgets are allocated or authorized for both functions regarding the same issue at the same time. Attempts to estimate the separate effects of research and extension using the regression analysis often fail.

Fourthly, all *ex post* analyses were based on data since World War I when fossil fuel was cheap and abundant. Since the likelihood of having cheap and abundant fossil fuel in the future is very slim, the estimated relationships may not be relevant in predicting or planning for the future.

This study proposes an alternative approach to overcome the above difficulties. The purpose of this study is to describe proposed methodology and procedures to estimate the separate rates of return to research and extension in U.S. agriculture using an *ex ante* analysis.

The Process of Technological Innovation

The process of technological innovation starts with an idea or confrontation of a problem and ends with widespread adoption of the technology throughout an industry or a market. This process can be divided into two periods: (1) the creation of a new technology and (2) dissemination of this technology.

During the first period, after an idea is initiated and resources are committed to conduct research, a theory is proposed to solve the problem and experiments are conducted to confirm the validity of the proposed theory. When the first primitive model or the prototype of a new technology (which can be a new product or a new process) is developed, it is tested in the laboratory and later tried under field conditions. If the field trials prove to be successful, a new technology is created. During this period of research, resources are committed, but no extendable technology is created. Thus, no effects on productivity can be felt. The length of this period, a leadtime, varies from one technology

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In the second period, a new technology is ready for commercial introduction. This is when time extension comes into play. During this period, extension agents are busy teaching farmers the new technology and conducting field demonstrations. Initially, only a small number of farmers adopt the technology because the possible payoff of the new technology is uncertain and the potential early adopters need time to learn how to use the new technologies.

As early adopters benefit from using the new technology, more and more farmers will be attracted to it. As a result, the percentage of adoption increases exponentially. Eventually, as most potential adopters adopt the new technology, the percentage of adoption will level off and approach a maximum. For the purpose of this study, the period between the commercial introduction to the time the percentage of adoption reaches the maximum is called an adoption lag. The length of adoption lag also varies with different technologies. With increased funding for extension, it is possible to shorten the adoption lag and/or increase the percentage of adoption.

The above technological innovation model is a simplified one. In reality, the dividing time for the two periods is not clear cut. Furthermore, even before the completion of research, some information about the new technology is diffused to farmers. Rosenbert (1976, p. 76) observes that:

> Innovation is, economically speaking, not a single well-defined act but a series of acts closely linked to the inventive process. An innovation acquires economic significance only through an extensive process of redesign, modification, and a thousand small improvements which suit it for a mass market, for production by drastically new mass production techniques, and by the eventual availability of the whole range of complementary activities, ranging, in case of the automobile, from a network of service stations to an extensive system of paved roads.

That is, a single technological breakthrough that may consist of many minor technologies developed over a period of years. For example, the first substantial commercial-scale application of research results on hybrid corn did not occur until the thirties, although serious research on hybrid corn began early in the century (Mansfield 1966, p. 122). In 1906, G. H. Schul, a geneticist at Cold Spring Harbor, New York, started experiments on heredity in corn (Sprague 1962, p. 106). Many state and federal inbreeding and hybridization

Burr-Leaming, was released and recommended by the Connecticut Agricultural Experiment Station. Hybrid corn technology has involved almost continuous developments of new hybrids. Thus, there has been a considerable overlapping of leadtime and adoption lag.

For simplicity, the first substantial large-scale introduction of a technology is considered a dividing time for the two periods.

Procedures

To obtain information needed to estimate the separate rates of return to research and extension, we plan to conduct a mailed Delphi survey and to hold two Delphi workshops. The Delphi technique is a systematic procedure for eliciting and collecting information from a panel of "experts". Two major characteristics which are distinct in the Delphic technique are feedback and anonymity (Linstone and Turoff, 1975). During the "Delphi Exercises", information from the summary of the responses is fed back to the experts for review. Each expert may contribute more information or take a different position. Through iterative processes of evaluation and re-evaluation, a consensus can be reached.

The most commonly used Delphi is a paper-and-pencil version. In this process, a questionnaire is mailed to the experts. After the questionnaire is returned, the responses are collated and the summary of the group's responses is fed back to the experts for re-evaluation. Another form of Delphi is a Delphi conference or workshop where the group's responses are processed by a computer programmed to carry out the compilation of the group results. Thus, the summary of the group's responses can be fed back to the experts immediately for re-evaluation.

In conducting a Delphi study, special attention should be given to the procedures used in selecting experts to ensure selection of an unbiased panel possessing expertise in the required areas. Bregman, Katz, and Salasin (1977) identified several possible problems which might be encountered in selecting experts to serve on the Delphi panel and provided useful guidelines to solve the problems.

To minimize delays in mailing questionnaires back and forth to the experts and to reduce the cost of holding long workshops, this study proposes to use a combination of one mailed Delphi and two workshops.

Identification of Emerging Technologies

Based on past studies and literature review, we will compile a preliminary list of emerging and productivity in the next 50 years. Then, a questionnaire will be developed and mailed to 50 scientists for additions to and modifications of the list. Through Delphi processes, the technologies which could produce unprecedented impacts on agricultural production, resources use and the environment will be selected.3/

A Workshop On Emerging Technology

About 30 agricultural scientists having expertise in future agricultural technologies will be invited to participate in a four-day Delphi workshop. The participants include specialists in specific future technologies and some "generalists."

Prior to the workshop, the list of emerging technologies and their background information will be distributed to all participants. For each future technology, a lead scientist will be selected and asked to prepare a short, nontechnical statement about the technology--what it is, areas of research, the probable year of commercial introduction, crops and livestock that will be affected, how it will affect productivity, and the effect on resource use, environment, and size of farms.

The lead scientists will present this information at the beginning of the workshop to stimulate thinking and discussion. The current and recent funding of research for each technology also will be provided to the participants.

For each technology, the panel of scientists will be asked to identify the affected crops and livestock and to estimate the effect on agricultural production (yields, livestock reproductive and feeding efficiency, etc.), resource use, and environment from the introduction and adoption of the technology. Under the assumption that recent trends in research funding for these technologies will continue into the future, the panel of scientists will be asked to estimate the year that a given technology will be introduced. Then they will be asked how much additional research funding will be needed to speed up the introduction of a given technology for a specific number of years.

Delphi Workshop on Technology Adoption

About 20 extension specialists will be invited to participate in a three-day workshop to estimate an adoption profile for each unprecedented technology identified in the previous workshop. Prior to the workshop, each participant will be given a list of technologies along with background information about the technologies. The information includes description of the

Under the assumption that current extension budget for disseminating new technologies continue into the future, the panel will be asked to estimate the length of adoption lag (from commercial introduction to the time the maximum percentage of adoption is attained), the percentage of adoption, and factors which impede adoption. With increased funding for extension, the panel will be asked to estimate how many years the adoption lag can be shortened and how much the percentage of adoption can be increased. Through Delphi processes, a consensus about the estimates can be obtained. Based on the information from the workshop, the adoption profiles (S-shaped curves) will be estimated for each technology.

Contributions of Research and Extension

As discussed above, research and extension enter to the process of technological innovation at different points of time, but they are complementary. Research results must be disseminated and adopted by farmers to affect agricultural productivity. Extension activity helps speed up the adoption process and increase the percentage of adoption. Thus, the effect of a given technology on agricultural productivity depends on the level of extension activity. On the other hand, the effectiveness of extension depends upon the effectiveness of research. Without research, no new knowledge can be extended by extension agents. Therefore, research and extension are interrelated and complementary. To estimate the separate contribution of research and extension, we rely on the partical analysis, i.e., holding extension at a certain level while we estimate the contribution of research. Likewise, in estimating the contribution of research, the level of extension is held constant.

The Rate of Return to Research

Suppose a given set of research resources is invested in the production of a particular technology in time 0 and the research is completed and a new technology is successfully developed in time m. During this period. research resources R_{1t} (t = 0, 1,...., m) are invested in each time period.

At time m, extension comes into play. As indicated earlier, the percentage of adoption is assumed to increase along an S-shaped growth curve as shown in Figure 1. At time n, the percentage of adoption reaches a maximum. The adoption lag is n - m.

If additional research resources are invested to provide scientists more support and equipment

($t = 0, 1, \ldots, m'$; $m' < m$). With the same level of extension activities, the adoption curve shifts from A_1 to A_2. The difference in the adoption profiles due to additional research expenditures is shown in Figure 2.

Introduction of a new technology may affect many commodities. For example, enhancement of photosynthetic efficiency may be applicable to soybeans as well as corn, sugar beets, sorghum, and many other crops. Let A_{1jt} be the percentage of adoption of the technology on the jth commodity at time t (i.e., t-m years after commercial introduction) before investing additional research expenditures, a_{2jt} the percentage of adoption after investing additional research expenditures, v_j the net increase in the value of producing the jth commodity when the technology is wholly adopted. Then, the net increases in the values of producing the jth commodity at time t before and after additional research investments are, respectively,

$$V_{1jt} = a_{1jt}v_j$$

and

$$V_{2jt} = a_{2jt}v_j$$

Thus, the marginal income increase in the value of producing the jth commodity at year t due to added research investment is

$$V_{2jt} - V_{1jt} = (a_{2jt} - a_{1jt})v_j$$

Since research and extension enter into the process of technological innovation at different points of time, to compute the rate of return to investment in research involves comparison of benefits received and costs incurred at different periods. Suppose we want to compute the ex ante rate of return at time m' when the research with increased level of expenditures is just completed. To be comparable, the costs incurred in the past (from time 0 to time m') must be compounded, while the benefits expected to receive in the future (from time m' to time n) must be discounted to present values.

Let C be the sum of the stream of additional investment in research compounded at the rate of r percent annually to the year m' and B_j the present value of the sum of the stream of future marginal returns for the jth commodity, then

$$C = \sum_{t=0}^{m'} (R_{2t} - R_{1t})(1 + r)^{m'-t} - \sum_{t=1}^{m-m'} R_{1t}/(1+r)^t$$

and

$$B_j = \sum_{t=0}^{n-m'} (V_{2jt} - V_{1jt})/(1 + r)^t$$

$$B = \sum_{j=1} B_j = \sum_{j=1} \sum_{t=0} (V_{2jt} - V_{1jt})/(1 + r)^t$$

Therefore, the marginal internal rate of return (r) to research can be obtained by solving the following equation for r:

$$\sum_{j=1}^{P} \sum_{k=0}^{n-m'} (V_{2jt}-V_{1jt})/(1+r)^t - \sum_{t=0}^{m'} (R_{2t}-R_{1t})(1+r)^t$$

$$- \sum_{t=1}^{m-m'} R_{1t}/(1+r)^t = 0$$

The Rate of Return to Extension

In estimating the contribution of extension on agricultural production, the level of research expenditures is held constant. By varying the level of extension expenditures, the marginal contribution of extension can be estimated. Let E_{ijt} be the extension expenditures spent on disseminating the jth new technology in year t with i=1 denoting before and i=2 after investing additional expenditures.

An increase in extension activities can either increase the percentage of adoption, or shorten the adoption lag, or both. Figure 3 illustrates the case where increased extension expenditures increase the percentage of adoption for any given time, but the length of adoption lag and the maximum percentage of adoption remained unchanged. In the second case, shown in Figure 4, an increase in extension expenditures increases the percentage of adoption at any given time and the maximum percentage of adoption, but the length of adoption lag remains the same. In the third case (Figure 5), an increase in extension expenditures shortens the adoption lag but the maximum percentage of adoption remained unchanged. In the fourth case, an increase in the extension expenditures increased the percentage of adoption as well as shortens the length of adoption lag (Figure 6). In either case, the marginal contribution of extension on the jth commodity at a given time t is measured by the product of the net increase in the value of producing the jth commodity (v_j) and the vertical distance between the two adoption profiles ($a_{2jt} - a_{1jt}$):

$$V_{2jt} - V_{1jt} = (a_{2jt} - a_{1jt})v_j$$

The present value of the total increase in extension expenditures for the ith commodity is

$$C_j = \sum_{t=0}^{n-m} (E_{2jt} - E_{1jt})/(1 + r)^t, \text{ for cases 1 and 2}$$

and

$t=0$ $t=n'-m$

cases 3 and 4

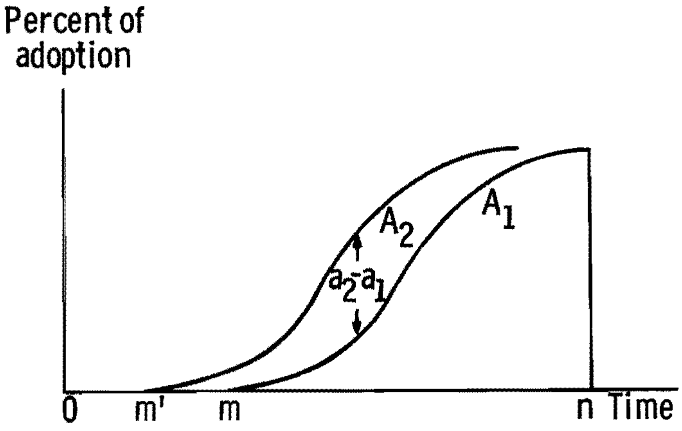
The present value of the total increases in extension expenditures for all the commodities are

$$C = \sum_{j=1}^{P} C_j$$

The internal marginal rate of return to extension (r) can be obtained by solving the following equation for r

$$\sum_{j=1}^{P}\sum_{t=0}^{n-m} (V_{2jt} - V_{1jt})/(1 + r)^t - \sum_{j=1}^{P} C_j = 0$$

Figure 1. A Change in the Year of Commercial Introduction Due to Increased Research Expenditures.



Research Expenditures

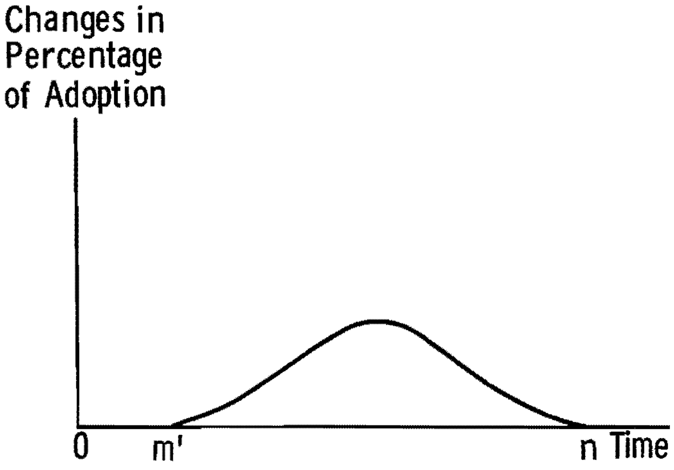
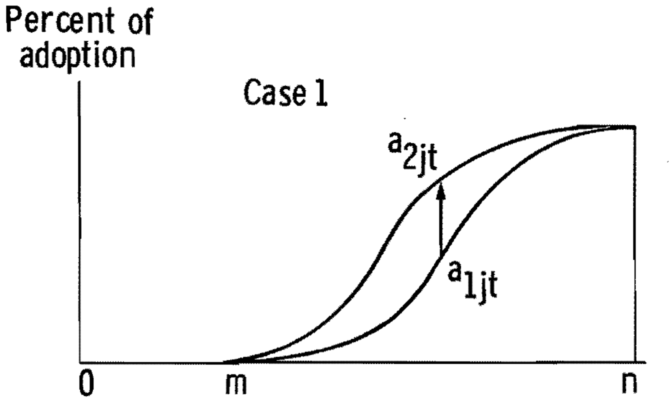


Figure 3. A Change in the Percentage of Adoption Due to Increased Extension Expenditures.



Increased Extension Expenditures

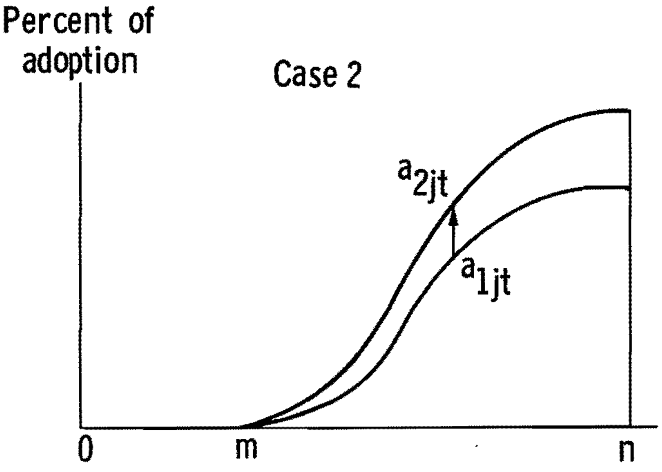
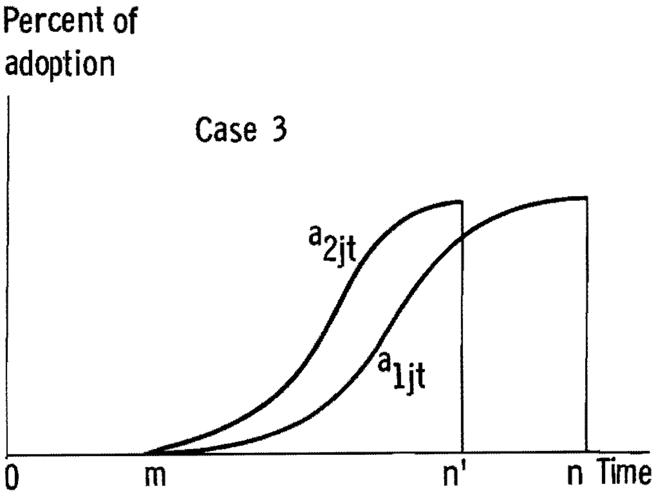
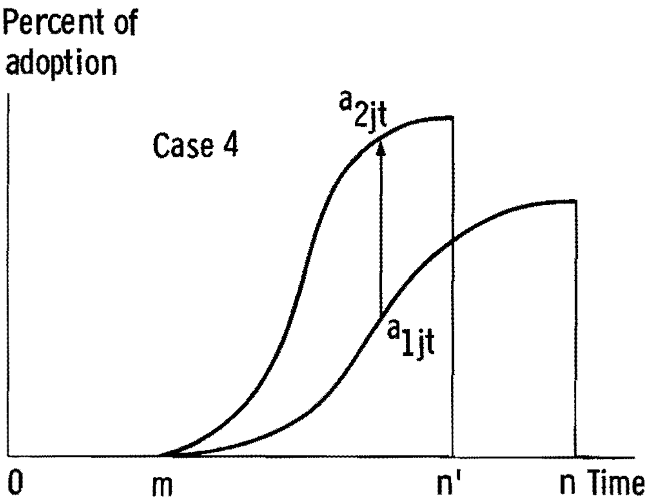


Figure 5. A Change in the Adoption Lag Due to Increased Extension Expenditures.



Due to Increased Extension Expenditures.



Summary

This paper describes proposed methodology and procedures to estimate the *ex ante*, separate internal rates of return to research and extension. The methodology is based on the observations that increased research expenditures will lead to creation of new technology or shorten the leadtime for an emerging technology and increased extension expenditures will either increase the percentage of adoption of a new technology or shorten the length of adoption lag, or both. If appropriate information is available, it is possible to estimate the separate effects of research and extension.

Generally, research and development leadtimes and technology adoption lags are lengthy and good *ex post* information on the separate marginal effects of increases in research expenditures on leadtime length and increases in extension expenditures on adoption lags is not available. This study proposes to use an *ex ante* approach to collect this information.

One mailed Delphi survey and two technology workshops are planned to obtain information about the effects of increased research and extension expenditures on the production and adoption of new technologies. The mailed Delphi survey identifies emerging technologies which are expected to have unprecedented impacts on agricultural production in the next 50 years. In the emerging technology workshop, a panel of scientists will estimate changes in the date of commercial introduction of a new technology in changes in the adoption profile due to increases in extension expenditures will be estimated. From the above information, the separate rates of return to research and extension can be computed.

Footnotes

1/An ex ante analysis is based on subjective information rather than historical observations. This paper describes the methodology and procedures for using an ex ante analysis to estimate the rates of future return to research and extension.

2/See George Norton and Jeff Davis (1979) and Robert J.R. Sim and Richard L. Gardner (1978) for reviews of literature on research and extension evaluation in agriculture.

3/Information on resource use and environment will be used in the evaluation of the impacts of emerging technologies in later studies.

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Returns to Social Science Research: Issues and Possible Methods

George W. Norton and G. Edward Schuh*

Several approaches have been employed over the past 25 years to evaluate returns to agricultural research (see Schuh and Tollini and Norton and Davis for recent reviews of the literature). Many studies have provided estimates of returns to aggregate agricultural research, to agricultural commodity groups, and to individual agricultural commodities. Those that have provided estimates of returns to specific technologies, research projects, and research programs have concentrated for the most part on applied production oriented research such as plant breeding (Griliches, Kislev and Hoffman). Few studies, however, have attempted to quantitatively evaluate the returns to non-production oriented research such as social science research. The purpose of this paper is to explore possible methods for conducting such an evaluation. We begin by presenting data which highlight the importance of social science and related research relative to total agricultural, forestry, and home economics research. We then briefly discuss the problems inherent in its evaluation and suggest a conceptual framework for measuring its value. Empirical means of estimating economic returns to social science research are examined followed by an application of decision theory to agricultural economics research evaluation.

The Magnitude of Social Science Research

Social science research commands a significant share of total research dollars spent on agricultural and related research. The Current Research Information System (CRIS) provides research expenditure data categorized by Research Problem Areas (RPAs). Out of the total 100 RPAs in this classification system, we have identified 34 which pertain primarily to social science research (see Table 1). In 1977 out of a total of $1,032 million spent on research by the state agricultural experiment stations, USDA, forestry schools, and other cooperating institutions, approximately $98 million was spent on social science-related research or about 9.5% 1/. Many of the RPAs are related to agricultural economics. Agricultural economists have spent a good deal of effort evaluating returns to agricultural research but little of this effort has been directed toward evaluating agricultural economics research. RPAs 108, 114, 316, 501, 503-511, 601-604, 807, and 808 all appear to involve agricultural economic research components and total over $54 million, about 5% of total agricultural and related research.2/

There are also several research problem areas which are primarily nonproduction and nonsocial science oriented but may contain small amounts of social science research (See Table 2). Expenditures on these research categories of which watershed protection and management and human nutrition are the largest totaled $98.4 million in 1977 or about 9.6% of total agricultural and related research.

Problems Inherent in Social Science Research Evaluation

The lists of research problem areas in Tables 1 and 2 suggest the first problem inherent in social science research evaluation. There are many different types of research with a variety of hard-to-measure outputs. Some of the research projects are not directed toward increasing agricultural output or farmers' and consumers' incomes. They are concerned with improving nutrition, preserving the environment, reducing hazards to the population, or affecting other societal goals. Those RPAs that are concerned partly with economic growth or income distribution usually generate research output which impacts very differently than production-oriented research. Production oriented research such as plant breeding, plant pathology, animal breeding, etc. for the most part result in increases in bushels or pounds of production due to improved quality of inputs. Social science research, on

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RPA	Title	No. of Projects	Scientist Years	Funds
108	Econ and Legal Prob. of Water Mgt	47	18.4	$ 1,276,131
114	Rsch on Mgt of Research	27	10.8	747,865
303	Econ of Timber Prod.	55	29.1	1,957,993
316	Farm Business Mgt	139	49.4	2,808,506
501	Improvement of Grades and Stands	97	45.0	4,230,424
502	Marketing of Timber Products	39	41.9	2,791,382
503	Marketing EFF of Agr Prod & Inputs	315	118.5	7,933,989
506	Supply, Demand, Price Analysis	209	130.0	7,886,333
507	Competitive Interrelationships in Ag	66	20.6	1,035,489
508	Domestic Market Development	66	22.4	1,312,333
509	Performance of Marketing Systems	202	113.3	6,665,945
510	Group Action and Market Power	69	26.7	1,405,424
511	Improve. in Agr. Stats	31	11.9	986,643
512	Improve. in Grades & Stands of Forest Products	20	13.6	874,151
513	Price Anal. Forest Products	20	13.5	923,537
601	Foreign Market Development	79	93.9	4,887,684
602	Eval. of Foreign Food Aid P.	3	.3	22,251
603	Tech. Assist to Dev Countries	61	29.6	1,730,844
604	Prod Devel & Mkts, Foreign Mkts	27	27.7	2,009,764
703	Food Consumption Habits	214	112.4	9,600,767
705	Select and Care, Clothing and Tex.	65	21.8	1,064,590
801	Rural Housing	62	29.0	2,130,263
802	Indiv. & Family Dec. Making	169	35.1	2,386,525
803	Rural Poverty	44	9.4	596,787
804	Improve Econ Pot. of Rural People	119	32.0	2,157,872
805	Commn. & Ed. Processes, Rur. People	139	29.6	2,762,300
806	Ind. & Fam Adjust to Change	185	59.0	4,298,096
807	Struct Change in Agr	138	77.3	7,142,478
808	Gov't Prog to Bal Farm Output & Demand	51	32.4	1,939,024
902	Outdoor Recreation	184	63.1	4,786,814
903	Multi-use, Forest Prod.	85	31.7	2,563,113
907	Improve Income Opp. in Rural Com.	193	57.2	3,550,863
908	Rural Institutional Improvement	317	97.5	6,495,301
	Subtotal, Social Science and Related Categories			98,212,481
	Total, All Research Problem Areas			$1,031,711,787

the other hand, seldom affects quality of inputs directly.

Furthermore, it is difficult to determine the causality of changes which occur following social science research. It is easier to link yield effects to plant breeding research than it is to ascertain that changes in farmer behavior or in institutions are due to research which suggested those changes. Related to this is the fact that information is available to farmers from sources other than public research and extension. Farmers rely on their experience and private sources of information as well. (Eisgruber, 1973, summarizes sources of information for Indiana and Illinois farmers).

In addition, there is a certain degree of complementarity between some types of social science research and biological and physical research which is difficult to quantify. Many of the problems of social science research evaluation relate to the measurement of output. In the next section, we suggest conceptual bases for making such measurements.

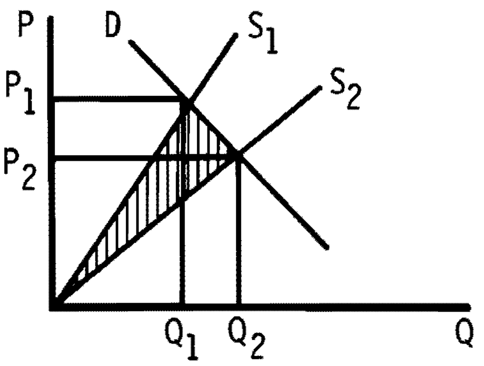
RPA	Title	Projects	Years	Funds
107	Watershed Protect. and Mgt	287	245.2	$ 27,467,000
306	Prod. Mgt Sys. for Fruits and Veg.	86	22.0	1,694,113
309	Prod. Mgt Sys. for Field Crops	204	52.3	4,796,797
313	Prod. Mgt Sys. for Animals	288	67.2	10,045,385
701	Toxic Res. in Food	224	102.2	8,994,496
702	Food Prot. from Toxins	251	147.5	11,363,865
704	Home and Commercial Food Service	58	17.9	1,259,364
706	Control of Insects Affecting Man	136	71.3	6,781,747
707	Prev. Trans. of Diseases and Par. to Man	32	8.1	745,755
708	Human Nutrition	469	217.0	19,716,663
709	Reduce Hazard to Health and Safety	115	90.0	6,567,490
	Total			$ 99,432,675

Conceptual Framework for Measuring the Value of Social Science Research

It would appear that a common thread running through most types of social science research is that the output is information rather than a new or improved product. In some cases, the information may lead to someone producing a better product but the research itself does not produce the product. For purposes of classification, the types of information provided by projects in the research problem areas listed in Tables 1 and 2 can be grouped into seven basic categories: (1) management information, (2) price information, (3) institutional information, (4) product and environmental quality information, (5) human nutritional information, (6) information to aid in adjusting to disequilibria, and (7) information to aid in reduction of rural poverty. Much of the information generated by research in these areas is directed toward goals of increasing economic growth due to greater economic efficiency, improving the relative position of rural poor, and furthering personal health and safety. Some projects are aimed at more than one goal and perhaps a few contribute little to any of these goals. Many of the projects, even those directed primarily at the second and third goals, would appear to have some effects which could be measured or at least conceptualized in terms of having an economic value. Therefore, we turn now to each of the seven information categories listed above and explore how the economic value of the information from the related research projects might arise.

(1) Management Information. Many social science RPAs are concerned with improving management to facilitate attainment of technical or allocative efficiency. The value of information on technical efficiency results from its potential to provide producers with improved knowledge of the true parameters of the existing or new technology for a particular commodity. The value of information on allocative efficiency results from its potential to provide producers with improved knowledge of the most profitable or utility maximizing combination of inputs and outputs given the technology and expected prices. In Figure 1, we illustrate the effects of improved technical efficiency on the market for a particular commodity.

Figure 1.

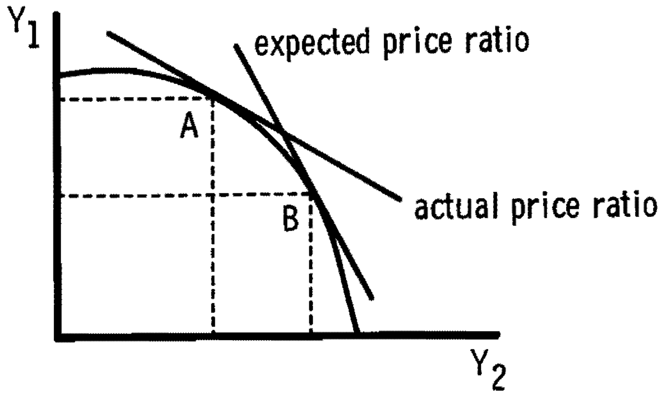


If producers combine inputs in such a manner that they attain improved technical efficiency, then there should be a shift in the production function for that commodity resulting from the improved timing of input usage, fuller exploitation of the complementary relationships among inputs, etc. This would result in a downward shift in the supply curve since it represents increased output from the same amount of inputs. This is a phenomenon similar to Finis Welch's

Figure 1 also illustrates the effect of improved allocative efficiency in use of inputs for a particular commodity. If management research enables producers to discover a lower cost combination of inputs to produce the same quantity, this should shift the supply curve down.

Figure 2 illustrates the effect of improved allocative efficiency in the choice of commodities to produce. If management research causes a movement from A to B, then benefits can be estimated as the increased profit resulting from this more efficient allocation of resources.

Figure 2.



(2) Price Information. The benefits to improved price information are illustrated in Figures 3 and 4. Assume producers estimate the price of the commodity to be P_1 which is above the equilibrium price P_e. In this case, they will produce a quantity of Q_1 which is larger than the equilibrium quantity Q_e. The resulting price will be P_1' and the resulting change in net social benefit will be A + B + C - (A + B + C + D) = D.

If economic research such as econometric modeling efforts lead to price forecasts which are closer to Pe, then this net social loss will be reduced. A similar argument could be made for the case where producers underestimate price (Figure 4). The change in net social surplus is - (A+B) + (A-D) = - (B+D).

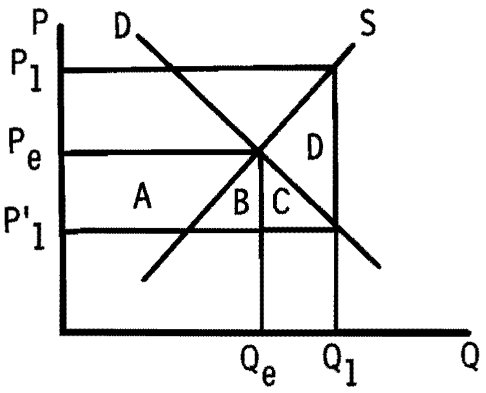
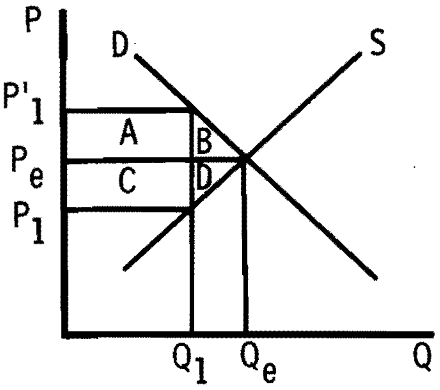


Figure 4.



(3) Institutional Information. Many types of social science research provide information on how certain institutions might be changed to function more efficiently or improve social welfare. The effects of this research depends on the type of institution being analyzed. The term "institution" can be defined as the set of behavioral rules that govern a particular pattern of action and relationships (Ruttan). If farm programs are changed as a result of agricultural policy research, this can be thought of as institutional change. Timing plays an important role in the resulting benefits to such research. In many cases with economic research, the welfare impacts of proposed institutional changes are estimated. Evaluation of that research then requires judgment as to the impact of the research on the subsequent institutional change.

(4) Product and Environmental Quality Information. For those goods for which quality can only be determined upon use, research on product quality and dissemination of the information can save the consumer costs that would have been incurred following purchase of a lower quality good. Whether these are actual cost savings or not, the end result will be that consumers obtain more utility from the bundle of goods they consume. They more correctly perceive the true shape of their utility functions resulting from consumption of the particular good for which information was provided. Since the consumer's

sult in an increase in net social benefits which then need to be weighed off against the cost of the research. In some cases, the research leads to government standards which eliminate the lower quality and sometimes hazardous good from the market. Direct benefits may be realized as lower medical costs if a hazardous good is removed.

(5) Nutrition Information. Research which leads to improved nutrition may cause a shift down in the supply curves for many goods and services due to a reduction in medical costs and increased labor productivity. Different types and amounts of food might be consumed following realization of the importance of certain nutrients and upon acquisition of information on the nutrient content of certain foods. In other words, nutritional information can affect the utility that a consumer perceives will be obtained from certain foods. This will result in a shift out in demand for certain foods and a shift in for others. Nutritional information can perhaps be thought of as a special case of the product quality case. Changes in net social benefits will result from the supply and demand shifts.

(6) Information to Aid in Adjustments to Disequilibria. Information which leads to more rapid adjustments to disequilibria results in more efficient use of resources so a greater bundle of goods can be produced with the same set of resources. Conceptual frameworks used to describe the benefits of management and price information can be used here with the added factor that returns realized today are worth more than the same returns realized tomorrow.

(7) Information to Aid in the Reductions of Rural Poverty. The value of research to reduce rural poverty is dependent in part on the weight placed on the equity goal. Rural poverty may also be partly a manifestation of a disequilibrium situation. To the extent that research efforts to reduce rural poverty have resulted in identifying its causes and recommending possible solutions, the benefits may be measured conceptually in terms of improvements in real income of the poorest segments of the rural populations.

Empirical Means of Evaluating Social Science Research

Eisgruber (1978) points out three approaches that have been used empirically to evaluate the value of information: the net social benefits approach, the decision theoretic approach, and the scoring approach. The conceptual framework in the last section lends itself most readily to the net social benefits approach. Eisgruber surplus has existed since the writings of Depuit, Hayami and Peterson were the first to use the approach in an analysis of the value of information. They examined the value of outlook information in the United States. Since then, Freebairn has extended this analysis to the evaluation of net benefits from more accurate price information.

The decision theory approach explicitly considers that the value of information is an outgrowth of the economic theory of uncertainty. Hirscheiffer points out that uncertainty is summarized by the dispersion of individual's subjective probability distributions over possible states of the world. Information consists of events tending to change these probability distributions.

The decision theoretic approach can be summarized as follows: A variety of actions are presumed to be open to the decisionmaker a_1, a_2, ... a_m. Several states of nature, S_1, S_2, ... S_n, are also possible and the decisionmaker has some knowledge of the likelihood (prior probability) of such states occuring, $P(S_i)$. With a given amount of knowledge, the decisionmaker will choose the action a_i^* which maximizes his expected utility. The expected utility of jth action is $\Sigma_i\ u(a_j|S_i)\ p(S_i)$. Now if additional information, Z_1, Z_2, ... Z_m, becomes available to the decisionmaker and he has knowledge of the probability of the information coming true, i.e., $P(Z_j|S_i)$, then Bayes Theorem can be used to derive posterior probabilities of states of nature occurring, $P(S_i|Z_j)$. By Bayes Theorem:

$$P(S_i|Z_j) = \frac{P(S_i)\ P(Z_j|S_i)}{\sum_i P(S_i)\ P(Z_j|S_i)}$$

The revised expected value of a_j is now $\sum_i U(a_j|S_i)\ P(S_i|Z_j)$. The value of the information is the difference between the maximum utility with and without the information and this can be compared with the cost of obtaining the information.

The major problem with using this approach is in the estimation of subjective probabilities in the prior and posterior situations. Because of difficulties in obtaining these probabilities the approach has been used primarily for microproblems. The appropriate utility function must also be determined unless a linear utility function is assumed so that maximizing expected profits is equivalent to maximizing expected utility (Eidman, Carter, and Dean).

With the scoring approach, scientists and/or administrators are called upon to weight alternative research projects or problem areas

Kaldor; Mahlstede; Shumway and McCracken for examples of scoring models used in agricultural research evaluation).

While there may be other means of evaluating returns to social science research, the three mentioned by Eisgruber (1978) appear to be among the most promising. In the next section, we provide an example in which the decision theory approach is used to evaluate returns to one type of agricultural economic research. This is followed by an illustration of how the net social benefits approach can be combined with the decision theory approach in research evaluation. An empirical example using the scoring approach is beyond the scope of this paper.

Application to Agricultural Economics Research

In this section we make use of decision theory to evaluate returns to price outlook information. Each fall agricultural economists at the University of Minnesota develop outlook statements for each of the major agricultural commodities in Minnesota. One part of the outlook projections is the expected price of each commodity over the coming marketing year. At the time the projections are made, the economists have a good idea of the size of current crops. They make price projections, therefore, based on the expected demand over the following months. They recognize that conditions change in unforeseen ways, but the outlook information provides a reference from which farmers can adjust their expectations. National and international factors are described in the outlook which might affect the price projections.

One of the crops for which outlook projections are made is soybeans. Each fall farmers must decide how to market their crop over the coming months. There are many different strategies open to them. Three common ones are: (1) to sell at harvest; (2) to store until spring, anticipating a seasonal price rise; and (3) to store at harvest, pricing the crop through the sale of futures. In this example, we illustrate how decision theory can be used to evaluate the return to soybean price outlook information developed to help farmers make this marketing decision.

The five components of a decision framework in which additional information is brought to bear on a problem are actions, states, calculation of a monetary payoff table, conversion to utility values, and estimation of prior and posterior probability distributions. In this example there are three possible actions:

a_1 = sell soybeans at harvest (October), a_2 = store soybeans and sell in the spring (May), and a_3 = store soybeans and sell in spring, but costs (by $.15/bu. or more); S_2 = the price in May just covers storage costs ($.15/bu. less to $.15 per bu. more); and S_3 = the price fails to cover storage costs (at least $.15/bu. less than covers storage.)

A time series of cash and futures prices as well as storage costs are shown in Table 3. These data can be used to develop the payoff matrix of returns relative to sale at harvest (see Table 3a).

Optimally, one would like to convert the values in the payoff matrix to utility values. In our example, we will assume linear utility which enables us to use the payoff table directly. The prior probabilities of states of nature occurring should be the decisionmaker's subjective probabilities without knowledge of outlook projections. Farmers have a variety of information sources they draw upon such as farm magazines, their experiences and records, etc. These subjective probabilities can be elicited through a variety of means (Anderson, Dillon, and Hardaker) and should be obtained in conducting an evaluation of this sort. In our example, however, we will assume that farmers base their expectations on historical seasonal price movements. Prior probabilities, $P(S_i)$, are developed from the historical probabilities for the last 15 years and are shown in Table 3a. These can then can be combined with the payoff matrix to determine the expected value of each of the three outcomes. If no additional information were available, action two would be optimal and would have an expected value of $.58 per bushel. This is found by multiplying each element in the payoff matrix by the appropriate $P(S_i)$ and then summing the values for each action.

Now, assume that farmers have access to the price outlook information. By looking at past outlook projections and actual states of nature which occurred, conditional probabilities can be developed $P(Z_j|S_i)$, *i.e.*, the probabilities of particular outlook projections given the states of nature which occurred in the past (see 3a). These conditional probabilities can then be used to calculate the posterior probabilities, $P(S_i|Z_j)$, *i.e.*, the probabilities of states of nature given the outlook by using Bayes formula $P(S_i|Z_j) = \frac{P(S_i)P(Z_j|S_i)}{\sum_i P(S_i)P(Z_j|S_i)}$. The joint probability, $P(S_i)P(Z_j|S_i)$, is the product of the prior and conditional distributions and $_i\ P(S_i)\ P(Z_j|S_i)$ is obtained by summing the joint probabilities over all S_i for a particular Z_j (see Table 3c).

Applying the posterior probabilities to the original payoff matrix gives the expected value

Year	October	May	Cost	Oct 15	May 15	Oct 15	May 15	(May)	Market	Market (July)	Net
67-68	2.53	2.67	.17	2.73	2.73	2.74	2.73	2.50	- .03	+ .01	- .02
68-69	2.44	2.66	.16	2.62	2.67	2.62	2.71	2.50	+ .06	- .04	- .03
69-70	3.32	2.63	.16	2.58	2.68	2.59	2.70	2.35	+ .15	- .11	+ .04
70-71	2.83	2.92	.19	3.07	2.98	3.07	2.99	2.90	- .10	+ .08	- .02
71-72	3.09	3.49	.20	3.34	3.50	3.35	3.54	3.50	+ .20	- .19	+ .01
72-73	3.21	8.76	.21	3.44	9.07	3.46	8.37	3.00	+5.34	-4.91	+ .40
73-74	5.82	5.39	.38	6.18	5.45	6.19	5.52	5.50	- .81	+ .67	- .14
74-75	8.34	5.20	.55	9.04	5.22	9.05	5.09	6.50	-2.59	+3.96	+1.37
75-76	5.06	5.15	.33	5.57	5.22	5.62	5.27	5.00	- .24	+ .35	+ .11
76-77	6.19	9.41	.41	6.36	9.83	6.33	9.74	6.00	+2.81	-3.41	- .60
77-78	5.01	6.94	.33	5.35	7.37	5.42	7.22	6.25	+1.60	-1.80	- .20
78-79	6.56	6.99	.43	7.07	7.23	7.07	7.39	6.50	0	- .32	- .32

[a] Mid month.

[b] Storage costs based on 9% interest and 1.4% storage loss which = .066% for seven months.

[c] 15th or closest date when market was open.

[d] After subtracting storage costs.

of each action. The optimal action where each Z is predicted is circled in this last matrix. The expected value of the optimal strategy is (2.49).4 + (.02).33 + (.15).27 = $1.046 per bushel. The value of outlook prediction compared to the situation where only the prior probabilities are used is $1.046 - $.584 = $.462 per bushel. It should be emphasized that this value of $.46 per bushel would be smaller if the average farmer's subjective prior probability distribution was more accurate than the distribution based on historical seasonal price movements which was used as a proxy.

One reason that the value of outlook information is so high is that the price of soybeans was extremely variable during the 1970s. During times of more stable prices, the value of outlook information would be less because the payoffs in the payoff matrix would be smaller. It is also necessary to predict states 1 and 3 correctly at least part of the time for the additional information to be valuable. To illustrate this point we can compare the value of the outlook predictions with that of the May soybean futures price in October. Conditional probabilities, joint probabilities, posterior probabilities, and expected values of using the posterior probabilities were developed for the May soybean futures for the same 12-year period. The resulting value of information was -$.15 per bushel. Table 2 shows why there was no return. In 10 of 12 years, the futures market predicted (as one would expect) that state 2 would occur, i.e., the price in May would just cover storage. In the other two years, it predicted that the price would more than cover storage (S_1) and, in fact, just the opposite (S_3) occurred. If decision-makers used both futures and outlook information, this would reduce the value of outlook information. It is also interesting to compare the value of a perfect predictor with the value of the outlook projections. If a perfect predictor was available, the posterior probability

States of Nature (S_i)	a_1	a_2	a_3	$P(S_i)$
S_1	0	2.49	-.10	.4
S_2	0	.02	-.07	.33
S_3	0	-1.55	.45	.27
Expected value of a_i using $P(S_i)$.	0	.584	.0936	

(S_i)	Z_1	Z_2	Z_3
S_1	.5	0	.5
S_2	0	.6	.4
S_3	0	0	1

c. Joint Probability Matrix P(S)P(Z/S)

	Observations		
Prior Probabilities $P(S_i)$	Z1	Z2	Z3
.4	.2	0	.2
.33	0	.198	.132
.27	0	0	.27
P(Z)	.2	.198	.602

d. Posterior Probability Matrix

$$P(S/Z) = \frac{P(S)P(Z/S)}{P(Z)}$$

Observations

(S_i)	Z_1	Z_2	Z_3
S_1	1	0	.332
S_2	0	1	.219
S_3	0	0	.449

e. Expected Value of Action Using Posterior Probabilities

	Actions			
Posterior Prob's	a_1	a_2	a_3	P(Si)
$P(S_i/Z_1)$	0	2.49	-.10	.4
$P(S_i/Z_2)$	0	.02	-.07	.33
$P(S_i/Z_3)$	0	.13	.15	.27

.996
.01
.04
1.046

Value of Outlook = 1.046-.584 = .46/bu

1/ Prior probabilities based on farmer looking at data for last 15 years.

Table 4. Payoff Matrix

Actions*

S_i	a_1	a_2	$P(S_i)$
S_1	-11.4648	2.0375	.25
S_2	-1.8614	.1372	.5
S_3	7.8733	-3.1754	.25
Expected value of A_i using $P(S_i)$	-1.8286	-.2159	

* Payoff values are in millions of 1978-79 dollars.

Table 5. Expected Value of Actions Using Posterior Probabilities

Actions

Posterior Probabilities	a_1	a_2	$P(S_i)$
$P(S_i/Z_1)$	-6.634	1.08164	.25
$P(S_i/Z_2)$	-1.8397	-.09584	.5
$P(S_i/Z_3)$	.65524	-1.0565	.25

with an expected value of (2.49).4 + (.02).33 + (.45).27 = 1.124. This value of information of the perfect predictor is 1.124 - .584 = .54.

Some words of caution are in order. First, a linear utility function was assumed. If farmers are concerned about risk as well as expected income, then this would affect the payoff matrix and the resulting value of information. Second, this analysis assumed that a correct prediction of state 1 is worth the same whether it occurs in a year when prices exceed storage by several dollars or by only 16¢. The expected value is the same but clearly the actual historical value was dependent on which years the outlook was correct.

For purposes of determining the aggregate value of this outlook information, it is necessary to determine total soybean sales affected by the outlook predictions. In an average year from 1969 to 1978 soybean production was 93.7 million bushels. It is very difficult to determine what percentage of farmers actually used outlook information. Eisgruber (1973) provides an estimate that 11% of farmers in Indiana and Illinois make use of the extension service for price outlook information. At the same time, very few farmers who use price outlook information from the university use only that information when making a soybean storage decision in October. However, other sources of information for farmers such as radio, newspapers, and farm magazines often base their price outlook on university projections. Therefore, for purposes of illustration assume that 10% of Minnesota soybean farmers use the university outlook projections exclusively and that these farmers also produce 10% of the Minnesota soybean production. This results in a value of soybean outlook information of 93.7 million x .46 x .10 = $4.3 million per year. One can compare this with the cost of doing the outlook research and extension. It appears that under any plausible cost assumption the return is extremely high.

The above example illustrates how the decision theory approach might be used to evaluate returns to social science research. It is oversimplified however, for a number of reasons. First, we have assumed that the farmers who use the outlook to decide whether to store receive either the price in October or the price in May for their soybeans. Second, it is likely that a smaller percentage of Minnesota soybean farmers use the outlook to make a hedging decision as compared to those who use it to make a storage decision. Third, and perhaps most important, we have assumed that the amount of soybean sales affected by the Minnesota outlook projections is small relative to total sales in either period. In other words, we assumed that the affected farmers faced perfectly elastic demand for their soybeans. In the remainder of this paper, we alter these assumptions and recalculate the value of outlook information.

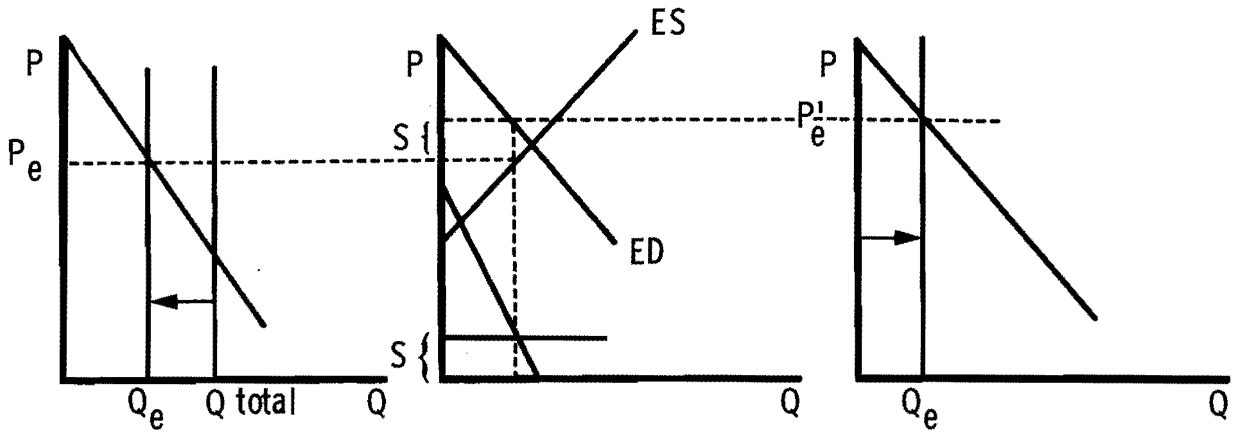
When one extends this analysis to the more general case and assumes that price is affected by sales activities of the farmers, he should then calculate the payoff in terms of changes in net social surplus. This must be done for each action-state combination in the payoff matrix.3/ How this would be done can be conceptualized with the aid of Figures 5, 6, and 7.

State 2 can be represented by Figure 5. The total supply of the commodity (Q_{Total}) would be allocated so that Q_e were sold in the fall and Q'_e in the spring. The eqilibrium price in the spring (P'_e) would be higher than the price in the fall (P_e) by an amount equal to the storage cost (S).

State 1 represents a situation when too much is sold in the fall (Figure 6). The observed price (P_2) would be below the optimum price (P_e) in the fall and above the optimum price (P'_e) in the spring. Consumers would gain A + B in the fall and lose C + D in the spring. The change in producer surplus would be E - A in the fall and -F + C in the spring.

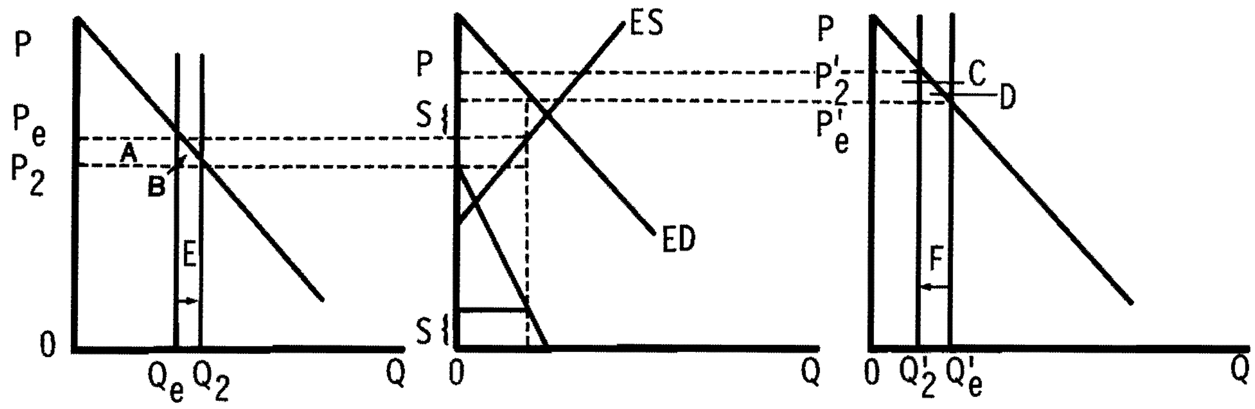
In the situation where state 3 occurs, too little is sold in the fall (Figure 7). The observed price (P_2) would be above the optimum price (P_e) in the fall and below the optimum price (P'_e) in the spring. Consumers lose A + B in the fall and gain C + D in the spring. The change in producer surplus is A - E in the fall and F - C in the spring.

Suppose farmers who use price outlook information sell 10% of the total production of the commodity. If they take action 1, i.e., sell all their grain in the fall, this would move the projected supply curve in the fall to the right by 10% of the projected spring sales. The effect on consumers and producer surplus can be calculated by comparing the old projected position of the fall supply curve to one 10% to the right for each state of nature, and the new projected position of the spring supply curve to one 10% to the left of the old projection. If farmers using outlook information took action 2, a similar analysis could be made with the curve shifting in the opposite direction. The projected original positions of the curves can be based on the observed location when each state of nature occurred over the past few years. One extension of this analysis would be to simulate the effect on benefits of varying the percentage of farmers



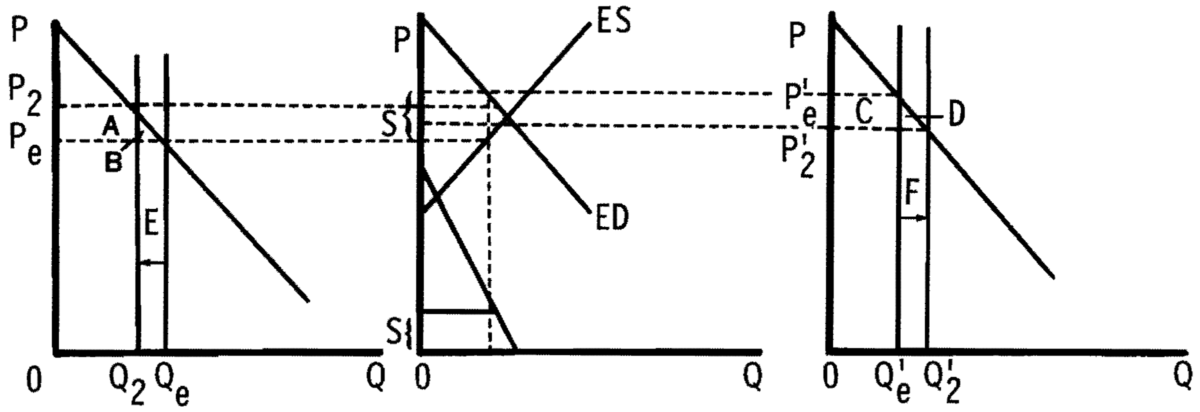
Supply & Demand, Fall | Excess Supply & Demand | Supply & Demand, Spring

Figure 6.



Supply & Demand, Fall | Excess Supply & Demand | Supply & Demand, Spring

Figure 7.



Supply & Demand, Fall | Excess Supply & Demand | Supply & Demand, Spring price is projected each fall at the University of Minnesota. Assume that farmers face the same states of nature described earlier in the paper 4/ and that they have the option of taking actions (1) selling all their beans at harvest in period t-1 (October), (2) storing beans and selling them during period t (November-June), (3) storing beans and selling them from July-September. Furthermore, assume that the outlook projections do not affect the quantities of beans sold in July to September. Assume linear demand curves for soybeans as represented in Figures 5, 6, and 7 and in Equations (1) and (2) below:

$$(1)\quad Q_t = a - bP_t \text{ or in inverse form}$$

$$P_t = \frac{a}{b} - \frac{Q_t}{b}$$

$$(2)\quad Q_{t-1} = \gamma - \beta P_{t-1} \text{ or in inverse form}$$

$$P_{t-1} = \frac{\gamma}{\beta} - \frac{Q_{t-1}}{\beta}$$

The Q_t, Q_{t-1}, P_t, and P_{t-1} are national quantities and prices. A fixed supply of soybeans is to be allocated between two periods, October (period t-1) and November-June (period t). The elasticity of demand for soybeans (e) is approximately -.3 (Houck, Ryan and Subotnik). Therefore,

$$e = b\,\frac{P_t}{Q_t} = -.3 \qquad e = \frac{\beta P_{t-1}}{Q_{t-1}} = -.3$$

$$b = -.3\,\left(\frac{Q_t}{P_t}\right), \qquad \beta = -.3\,\left(\frac{Q_{t-1}}{P_{t-1}}\right)$$

$$a = Q_t + b\,P_t \qquad \gamma = Q_{t-1} + \beta P_{t-1}$$

The consumer surpluses in the two periods are $CS_{t-1} = \int_0^{Q_{t-1}} P(Q)\;\partial Q$ and $CS_t = \int_0^{Q_t} P(Q)\;\partial Q$.

Total consumers surplus is $CS_t + CS_{t-1} = Z$.

$$(3)\quad Z = \frac{a}{b}\,Q_t - .5\,\frac{1}{b}\,Q_t^{\,2} + \frac{\gamma}{\beta}\,Q_{t-1} - .5\,\frac{1}{\beta}\,Q_{t-1}^2 - S_tQ_t$$

where S is the storage cost.

By maximizing (3) one gets the maximum net social surplus (A^{max}) as represented in Figure 5. Each year there is an observed net social surplus (Z^{obs}) represented in (4):

$$(4)\quad Z^{obs} = \frac{a}{b}\,Q_t^{obs} - .5\,\frac{1}{b}\,(Q_t^2)^{obs} + \frac{\gamma}{\beta}\,Q_{t-1}^{obs} - .5(Q_{t-1}^2)^{obs} - S_tQ_t^{obs}$$

$$(5)\quad Z^{max} - Z^{obs} \geq 0$$

beans).

Let Minnesota quantities be represented by $\hat{Q}_t$ and $\hat{Q}_{t-1}$. If farmers take action 1 and state 1 occurs, the following net social surplus results:

$$(6)\quad Z_{s_1}^{action\ 1} = \frac{a}{b}\,(\hat{Q}_t - .1\hat{Q}_t) - .5\,\frac{1}{b}\,(\hat{Q}_t - .1\,\hat{Q}_t)^2 + \frac{\gamma}{\beta}\,(Q_{t-1} + .1\hat{Q}_t) - .5\,\frac{1}{\beta}\,(Q_{t-1} + .1\,\hat{Q}_t)^2 - S_t(Q_t - .1\,\hat{Q}_t).$$

The payoff from this action 1, state 1 combination is $Z_{s1}^{action\ 1} - Z_{s1}^{obs}$ when the Q's and P's are historical values for the years when state 1 occurred. An equation similar to (5) must be set up for each action-state pair.

National and state soybean data for 1967-68 and 1978-79 were used to calculate the necessary quantities, prices, coefficients, Z's, etc. (See Appendix Table 1). A payoff matrix was assembled from the subsequent calculations (see Table 4).

Table 4. Payoff Matrix

Actions*

S_i	a_1	a_2	$P(S_i)$
S_1	-11.4648	2.0375	.25
S_2	-1.8614	.1372	.5
S_3	7.8733	-3.1754	.25
Expected value of A_i using $P(S_i)$	-1.8286	-.2159	

*Payoff values are in millions of 1978-79 dollars.

A new set of prior and posterior probabilities were calculated and the value of outlook information was calculated (see Appendix Table 2). The expected values of actions using posterior probabilities are shown in Table 5.

The resulting net social value of the outlook information is $602,200 (1978-79 dollars). This figure can be compared with the cost of providing the outlook information and a rate of

$100,000, the annual research cost would be $4,000. Additional costs are incurred for printing and extension activities, but the total annual cost would likely be under $10,000. There are also some costs associated with past research that provided a background for this analysis. The annual return is very high indeed.

Table 5. Expected Value of Actions Using Posterior Probabilities

	Actions		
Posterior Probs.	a_1	a_2	$P(S_i)$
$P(S_i \mid Z_1)$	-6.634	1.08164	.25
$P(S_i \mid Z_2)$	-1.8397	-.09584	.5
$P(S_i \mid Z_3)$	.65524	-1.0565	.25

The above example assumed that 10% of Minnesota soybeans are affected by the outlook information. The payoff was recalculated assuming the percentage was only 1%. The resulting value of information was $116,640 (1978-79 dollars), still a very high return to the outlook research and extension.

The decision theory and net social benefits approach could potentially be employed to evaluate other types of social science research. For example, it may be possible to evaluate certain types of policy research using a similar framework. It would be very important in such evaluations to specify the goals of the policy. A price support program and a particular support level suggested by research, for example, might be aimed at (1) maintaining farmers' income at a certain level, (2) maintaining low food prices, (3) minimizing the cost to the government (taxpayers), or some other goal. It is necessary to know the weights placed on these goals before one can measure the deviations from an optimum situation. Another problem with policy research evaluation is the difficulty in tying the causality of government action to research. There may be cases where research indicates a certain action would be optional from an economic standpoint but something else is done for political reasons.

Conclusion

There are a number of problems such as defining goals, measuring outputs, and determining causality between social science research and net social benefits approaches to provide quantitative estimates of economic benefits to certain types of social science research.

Footnotes

1/RPAs 705, 801, and 907 undoubtedly contain large non-social science-components as well.

2/It is difficult to know how much agricultural economics research is included in these RPAs without looking at specific projects. This 5% figure is most likely an upper bound since much of RPAs 108, 501, and 603 are probably not agricultural economics research.

3/In this case it is necessary to assume at the start of the analysis the amount of the commodity affected by the outlook information as this influences the level and distribution of gains and losses between producers and consumers. In the earlier example with perfectly elastic demand we worked with the per bushel payoffs and waited until the end to make the assumption about the amount of the commodity affected.

4/We assume however, that a deviation of $.10 from covering storage cost rather than $.15 defines these states.

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APPENDIX TABLE 1 - DATA

Crop Year	Mpls Price (Oct)	Mpls Price (Oct-June)	Mpls Price (Oct-June) Predicted	Average[1] Storage Cost (Nov-June)	US Price (Oct)	US Price (Nov-June)	US Quantity (Oct) (1000 bu)	US Quantity (Nov-June) (1000 bu)	MN Quantity (Oct) (1000 bu)	MN Quantity (Nov-June) (1000 bu)	Cos Ind
67-68	2.52	2.59	2.50	.11	2.44	2.50	272,416	573,147	18,206	37,113	2.1
68-69	2.44	2.53	2.50	.10	2.32	2.46	211,067	661,986	11,377	45,506	2.1
69-70	2.30	2.45	2.35	.10	2.23	2.39	320,573	685,670	16,722	45,605	2.0
70-71	2.83	2.90	2.90	.12	2.77	2.89	262,614	737,123	16,544	46,480	2.0
71-72	3.06	3.20	3.40	.13	2.96	3.03	291,673	756,233	11,509	42,840	1.9
72-73	3.21	4.81	3.25	.13	3.13	4.71	292,240	902,132	17,157	66,822	1.7
73-74	5.82	5.71	5.50	.24	5.63	5.24	294,003	1,055,424	22,394	80,867	1.4
74-75	8.34	6.46	6.50	.35	8.17	6.26	291,909	739,502	15,286	50,952	1.3
75-76	5.06	4.96	5.25	.21	4.92	4.65	311,024	999,609	17,739	61,101	1.1
76-77	6.19	7.64	5.70	.26	5.90	7.12	288,413	854,873	10,630	47,172	1.1
77-78	5.01	5.88	6.00	.21	5.28	6.02	324,163	1,226,181	21,414	95,023	1.0
78-79	6.48	6.68	6.50	.27	6.26	6.83	462,504	1,118,487	29,841	90,944	1.0

[1] Storage cost based on 9% annual rate of interest for an average of 4 months plus 1% loss and damage + .05 percent per month = 4.2% of the October price.

[2] Based on USDA cost of production index. Prices in this table are multiplied by this index before calculating payoffs.

Conditional Probabilities P(Z/S)

(S_i)	Observations		
	Z_1	Z_2	Z_3
S_1	.33	.33	.33
S_2	.167	.67	.167
S_3	0	.33	.67

Joint Probabilities P(S) P(Z/S)

$P(S_i)$[1/]	Observations		
	Z_1	Z_2	Z_3
.25	.0825	.0825	.0825
.5	.835	.3350	.0835
.25	0	.0825	.1675
P(Z)	.166	.5	.3335

Posterior Probabilities P(S/Z)

S_i	Observations		
	Z_1	Z_2	Z_3
S_1	.497	.165	.247
S_2	.503	.67	.25
S_3	0	.165	.502

[1/] Prior probabilities based on frequency of (S_i) from 1967-68 to 1978-79

PRINCIPAL ISSUES IN THE EVALUATION OF PUBLIC RESEARCH IN AGRICULTURE

Gordon C. Rausser, Alain de Janvry, Andrew Schmitz, and David Zilberman*

Introduction

Recent literature abounds with observations on the lack of public support for agricultural research and extension. As R. J. Hildreth notes in a recent AAEA Newsletter: "Administration-recommended decreases in formula funding in 1978-79 for the most part have been restored by Congress, but budget increases have been hard to come by." Hildreth draws support for his views from the recent work of Paarlberg who argues that agrarianism, while not dead, is diminishing at an increasing rate. Similar observations have been advanced by C. O. McCorkle who argues that the entire agricultural research structure is being increasingly challenged. The reasons he offers for this challenge include: (a) the visible output from current research lacks the spectacular aura of earlier achievements in agricultural research, (b) there is an increasing emphasis on immediately demonstrable results which have obvious implications for the level of support for basic research, (c) urban groups regard much of what is done in traditional research as peripheral to their interests, and (d) for any public investment in agricultural research, there are numerous conflicting goals, and no formal measurements have been advanced in any persuasive fashion to resolve these conflicts. Moreover, in the popular media, there is a growing disenchantment with public research which is thought in short run to benefit large, wealthy landowners, a few selected input manufacturers, or some of the major processors of agricultural products.

Much of the fire directed toward public research in agriculture comes from organized groups such as farm labor unions, small farmers, and consumer-interest organizations which often express the view that agricultural research activities tend to serve agribusiness interests. Their views seem to suggest that public funds are employed to distort income distribution in the agricultural and food sector toward those with large endowments and to enhance the concentration process among input suppliers, assemblers, processors, and distributors. They often argue --and in some instances correctly--that much of the research undertaken by the public sector should, instead, be made by the private sector. They argue that the public is simply subsidizing those who would otherwise undertake this research themselves--an instance of redistribution from the poor to the rich.

In the above setting, it is important once again to address the issue of what type of research should be supported by the public sector. In treatments of agricultural research evaluation, most analysts treat research as an aggregate without distinguishing the types that should be supported by the public sector from those types that should be supported by the private sector. In our analysis, we will find it useful to draw a distinction between three major types of research: basic-core, semibasic, and applied research. These three types of research will be formally defined. At this stage, it is important to recognize that the process of basic-core research defines the stock of knowledge; semibasic research expands, alters, and makes specific the existing stock of basic knowledge; and the results of applied research have the unique feature of entering actual production processes. The relationships among these three types of research are depicted in Figure 1.

The basic justification for public support of research in each of the above three categories is based, of course, on the notion of information as a public good. A wealth of literature on the economics of research and invention argues that there tends to be underinvestment in the private sector for such activities due mainly to the imperfect appropriability of knowledge. Other justifications for public investment in research and inventive activities include, inter alia, the distinction between public versus private risk preferences (Arrow

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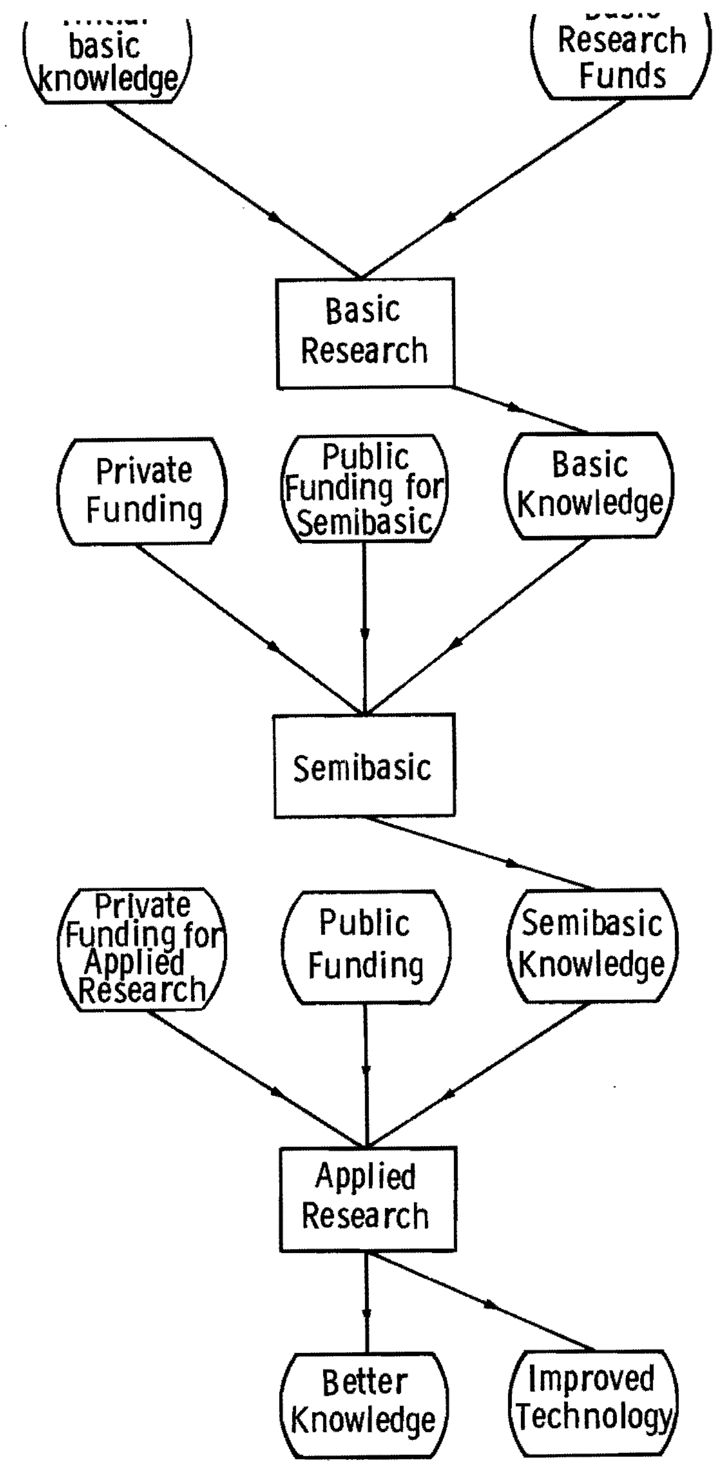


and Lind), the distinction between public and private discount rates (Marglin, Rawls), the magnitude of uncertainty, and the economic life of generated knowledge. Other reasons for public investment in research requires evaluations of the structure, conduct, and performance of the private sector; market distortions resulting from technological change; returns to the scale of knowledge accumulation; and the kind of incentives that exist for coalitions or group actions formed to support research in the private sector.

Given the above observation, a number of issues will be addressed in this paper. First, what is the decision basis for determining the "best" mix of private and public investment in agricultural research? Does this evaluation base differ for core-basic, semibasic, and applied research categories?

Second, while there certainly is some justification for the Arndt and Ruttan observation that "few of the available studies are free from methodological or empirical problems," is there any real support for their observation that "nevertheless, the overall robustness of the return figures do not appear to be in doubt?" If the rate of return and associated decision rules are found wanting, what alternative criterion decision rules in the context of both _ex ante_ and _ex post_ evaluations should be used? In this new framework, for both _ex ante_ and _ex post_ evaluations, what are the measurement requirements, _e.g._, of the research and development process, the general equilibrium effects, the time period for evaluations, the distributional effects across and within groups, competitive versus noncompetitive evaluations, and the like?

Third, once the mix of public and private sector investment in research has been determined, how do we operationally evaluate alternative research activities in the public sector? Contrary to many claims in the literature, we shall argue from an operational standpoint that the free-rider problems associated with the provision of public goods have never been solved, nor are they likely to be solved (Green and Laffont). In this context, our purpose will be to advance a framework which will be to maximize the social value of public goods while holding in check the free-rider problem.

The fourth and last set of issues to be addressed is motivated, in part, by a recent observation of T.W. Schultz with respect to the complacency and failure of economists to challenge "private patrons, foundations, and governmental agencies on their allocation of funds for economic research." Technology has social as well as economic dimensions. Since the growth and income effects of technology are determined not only by the nature of technology theory of induced innovations developed by Hicks, Fellner, and Ahmad which Hayami and Ruttan have applied to the case of agricultural technology. This theory needs substantial augmentation to explain the events that transpire during the process of technological advancement.

For example, in the case of the California agricultural sector, relative factor endowments are the result of a long history of public policy. Labor scarcity was overcome at first not by shifting to less labor-intensive crops but by increasing labor supplies largely through immigration policies of one sort or another. Only when these policies could no longer be pursued did attention turn to mechanization. Hence, the drive toward mechanization may be seen as the product of a social process where landowners use their wealth and political power to determine the direction of technological change. We shall argue that, if economists ever hope to provide truly useful analyses which will in some substantive sense influence the choices of public decisionmakers, they must understand, be able to explain, and even predict the behavior of the public sector in their support of agricultural research and extension activities. This forces us to examine the positive aspects of public investment in agricultural research and extension activities for which there are currently a number of alternative paradigms, inter alia, the theory of the state, the theory of economic regulation and governmental intervention, and the theory of endogenous governmental behavior. Once such positive aspects are fully understood, a number of creative opportunities will exist for altering the normative analysis associated with the first three sets of issues addressed in our paper.

Public Versus Private Research in Agriculture

In order to address the first principal set of issues outlined above, as well as the remaining sets of issues, we must first conceptualize the process of research and development. As suggested above, we shall find useful the distinction between core-basic, semibasic, and applied research. These categories represent stages of the research process and are distinguished as follows. Basic-core research is the search for general knowledge without regard to its ultimate usefulness. Semibasic research is also a process of search for principles, but it is targeted toward potentially applied areas. Here the basic-core stock of knowledge is taken as given; and attempts are made to alter its appropriateness, quality dimensions, and other characteristics. Applied research is explicitly designed to improve production possibilities and to improve information sources for economic decisionsmaking. Applied research results in either embodied or disembodied technological changes. Applied

release of the new technology. As Hirshleifer notes, the pecuniary effects may serve as incentives for private investment in research since the innovator who arrives first with the information is able, through speculation or resale of information, to capture the pecuniary effects.

In the case of each of the above stages of research, there are a number of important areas of agricultural research and development that can be distinguished. These include biological, chemical, mechanical, economical, informational, and managerial. Some examples of research topics according to stage and type of research are given in Table 1. This list is most certainly not meant to be exhaustive. The distinguished areas and stages of research, however, are particularly useful for drawing inferences about those research activities that should be conducted by the private sector and those that should be conducted by the public sector. Each of these areas of research and its associated research activities are distinguishable in terms of their patent enforceability, economic life, technological versus pecuniary effects, and the ability of rivals to imitate the research and development processes. These characteristics will determine, in large part, whether the net benefits of research and development activities can be captured by the private sector. To the extent that such benefits can be captured, the public sector should not be involved in such research and development activities. Obviously, given the definition and associated distinguishable areas of research for the core-basic stage, only the public sector can be expected to make investments during this stage. However, in the case of semi-basic and applied research, the optimal mix of public versus private research investments becomes an important issue.

For all areas of research, the public sector should support basic-core research. For the two remaining stages, a number of important distinctions can be made. First, in the case of chemical research activities, a mix of public and private sector research can be justified during the stage of semi-basic research. However, in the case of applied research, the private sector can and does assume much of the responsibility for research and development activities. This is due in large part to the short economic life of such activities in the chemical industry over which much, if not all, of the benefits accrue to the innovator. Moreover, there is a fair amount of concentration in the chemical industry; as Kamien and Schwartz observe (p. 24), intermediate concentration ratios seem the most conducive to research effort and success, while extreme concentration ratios activity increases more than proportionately with farm size (p. 32), "the bulk of empirical findings do not support it, with the notable exception of the chemical industry."

In the case of mechanical research activities, once again we find that the bulk of applied research should be undertaken by the private sector. This result occurs simply because the characteristics of economic life, technological and pecuniary effects, for this area of research are swamped by the patentability, enforceability, and obstacles to imitation for such research activities. For biological research activities not subject to the Plant Variety Protection Act, it is likely that an underinvested, stagnant equilibrium will arise in the private sector due to the ease of imitation and the lack of patent enforceability. Thus, much of the socially desirable biological research undertaken during the semibasic and applied stages should be supported by the public sector. For economical, informational, and managerial research and development activities, again difficulties arise in individual innovator's attempts to capture the net benefit of any particular innovation. Thus, one may expect underinvestment in this type of research from the private sector. Note, however, that there are some incentives for the formation of coalitions or groups in the private sector (e.g., commodity associations, research and development marketing organizations, and the like) to take advantage of the pecuniary externalities and returns-to-scale dimensions that arise from such research and development activities. As Hirshleifer notes (p. 573), a group of such individuals might willingly cooperate in making expenditures far in excess of the social value of the information to be acquired. Of course, when this type of collusion exists, public sector research and development (R&D) may be unnecessary.

In the above analysis, the key determinant of the desirability of public research is based on whether the private sector can capture sufficient benefits from the result of its research activities. Quite simply, if such benefits can be captured, then incentives exist for the private sector to make the appropriate levels of investment in R&D activities. Note, however, that this analysis ignores the possibility that public R&D research may be justified on still other grounds. Specifically, for those situations in which private research might have a detrimental effect on the structure of the industry, making a competitive structure noncompetitive, or a noncompetitive structure still more imperfect, a mix of public and private research may serve to preserve competition and/or reduce the amount of concentration.1/

such measures for R&D activities. While the rate-of-return analysis is useful at this juncture for illustrative purposes, it will be argued in the next section that such measures are flawed and that their popular use as an <u>ex post</u> measure of public research investment performance should be seriously questioned.

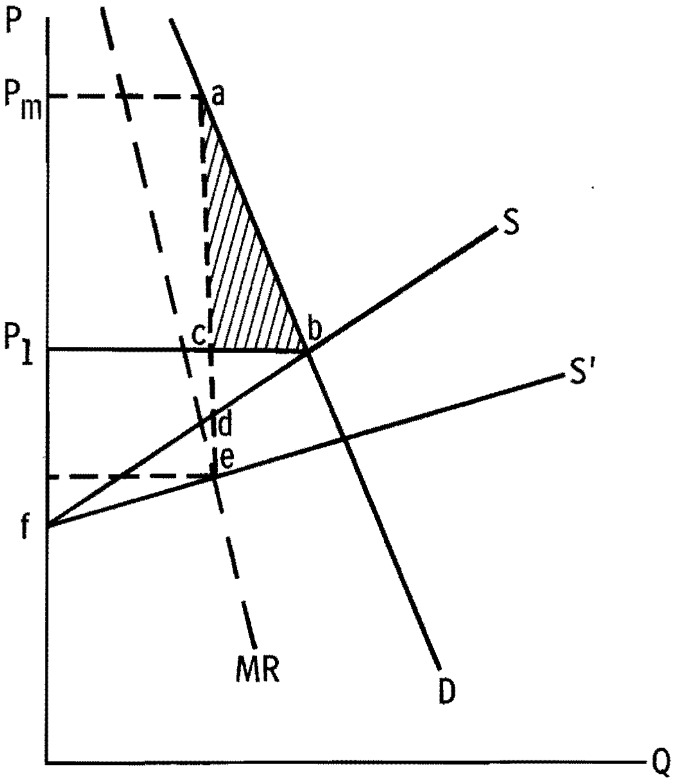
In the case of private investment in research development activities, Mansfield et al. have computed the private and social rates of return from such investments. In their simplest form, these computations for the private rate of return are simply the ratio of the change in economic rent to the private sector to the associated investments by the private sector, while the corresponding social rate of return incorporates the change in consumer's surplus. In the case of public investment, most agricultural economists have focused on the social rate of return from public investment.2/ Neglecting private investment, the social rate of return in the vast majority of these studies has been expressed as the change in economic rent to producers plus the change in consumer surplus relative to the level of public investment. However, much of the research conducted in agriculture involves both public and private investment, and thus the social rate of return should be based on the denominator which reflects this sum.

Interestingly, most of the research on rates of return to agricultural public investment focuses only on the change in consumer surplus and the change in economic rent to producers as measures of the benefits. However, at a minimum, a third component has to be explicitly recognized, i.e., input suppliers and/or market intermediaries (e.g., grain companies, fertilizer companies, feed companies, and the like). To accomplish this, the benefit measurements should be extended to include the change in economic rent to such groups. For the private rate of return, the Mansfield computation would be the ratio of the sum of the change in economic rents to producers plus the intermediate economic rents relative to the investment undertaken by the private sector. Note that, to include such considerations as the social cost to displaced workers from such technologies as mechanical, laborsaving techniques, the appropriate social rate of return would sum to four components relative to the sum of both private and public investment in research. These four components include the change in consumer surplus, the change in economic rent to producers, the change in economic rent to intermediaries, and the social costs imposed upon displaced labor. Finally, in many evaluations, it will prove useful to compare the rate of return to intermediaries resulting from the benefits accruing

What is important in the above analysis is the nature and extent of both public and private research costs. For example, in Mansfield's work, some of the high computed rates of return from private investment could be misleading if many of the benefits accruing to the private sector are the direct result of public investments. In other words, the benefits are due not only to private research activities but to public research activities as well. The private return from private investment can be quite high while the private rate from the joint public and private research can be quite low as can the social rate of return from joint investment.

For the competitive, full-employment paradigm, the social rate of return from private investment has to exceed the private rate of return. If the competitive assumption is relaxed, we can employ a simple static analysis to show that the private can exceed the public rate. Consider Figure 2 where P_1 is the competitive price before the innovation (Hueth, Schmitz, and Cooper, p. 15). If, after the innovation (supply S'), the industry can monopolize price at P_m, the social rate is situation is ($P_m acP_1$ + def) - bcd. However, the loss to consumers is $P_m abP_1$. Hence, from the gain in economic rents, there has to be subtracted the loss to consumers which makes the private return greater than the social return. It is important to point out that if area abd = def, the social rate is zero; and is abc > def, the social rate of return is negative even though the private rate can still be positive. In terms of Figure 2, a large private rate of return is possible even though the social rate is small or negative. Not only is a technological change brought about by private investment but, in addition, this change allows the private sector to engage in monopoly pricing.

Figure 2. Monopoly Pricing Resulting from Technological Change.



To illustrate the above framework, consider the well-known hybrid corn example. Studies have been done which show the rates of return from public investment and the speed of adoption of hybrids by farmers in the United States (Griliches). However, what is the link between public research and the use of its end results by producers and, ultimately, consumers? Assume for the moment that the largest funding for hybrid research comes from the public via experiment station research. The resulting product is a public good. But who obtains the benefits? Farmers do not buy new seed varieties directly from public institutions (e.g., experiment stations). Generally, seed is purchased by farmers from private seed companies. There are well over 100 small family-owned seed companies as well as extremely large companies such as Pioneer and De Kalb. How do the activities of these companies relate to experiment station research? This, in part, depends on the size of the seed company. The smaller companies, in that they do not try to develop new hybrid lines, generally do not engage in plant-breeding research. Essentially, the smaller companies sell hybrids developed by the public sector. The large companies also do plant-breeding research and thus sell hybrids that they develop. It is hypothesized that this research is tied in closely with the investments undertaken by the public sector.

The above observations can be supported by reference to the Green Revolution. Its success, to a large extent, depended not only on development of high-yielding crop varieties but also on irrigation and fertilizer which had to be provided. Here the spillover effects to the private sector of public research were clear. The demands for fertilizer, irrigation equipment, etc., substantially increased as a result of the introduction of new plant varieties; but what were their rates of return from public investment in research?

Research Types	Research Stages		
	Core-Basic	Semibasic	Applied
Biological	Genetic research	Recombinant DNA, cloning	Animal breeding
	Zoology	Veterinary medicine	Animal vaccines
		Entomology	Integrated pest management
	Botany	Plant pathology	Hybrid seeds
		Earth science	Crop rotation
Chemical	Biochemistry	Toxicology	Pesticides, herbicides
	Organic chemistry	Food preservation	Meat nitrate preservatives
Economical	Microeconomics	Econometrics	Empirical econometric modeling
	Welfare economics	Applied welfare	Cost-benefit analysis
		Agricultural economics	
Mechanical	Physics	Mechanical engineering	Farm machinery
	Metallurgy	Hydrology	Irrigation systems
	Geology		
Informational	Statistical theory	Applied statistics	Weather forecast
	Psychology	Decision theory	Crop and price forecasts
		Operations research	
	Electronics	Circuit theory	
		Computer design	Computer monitoring systems
Managerial	All of the above	All of the above	Improved practices

In the release of technology from public institutions, the issue of patent laws becomes crucial. Can hybrids be patented by the public sector? If they can (enforceably be patented), at what price should they be released to the private sector? It is of little use for the public sector to develop new hybrids and the like and never have them used by producers. Yet, in most cases, because of the competitive nature of stitutions and producers in the diffusion of technology.

This type of patent system affects the structure of the input supply industry in the following way. If the public institutions cannot patent innovations, they are available to large and small input suppliers alike. Because of the difficulty of patenting hybrids by public institutions, small seed companies have been able to exist along with the very large firms. If the university could patent hybrids, there would be a bidding process by the private sector for the rights to use the new product. This would probably result in a few large firms outbidding the small ones; hence, the seed industry, for example, would become highly concentrated. In addition, the seed companies themselves would do plant-genetic research, as Pioneer currently does, but to a greater extent if the rents from their new technologies can be captured and if the industry is noncompetitive. The ability to patent would be an additional factor that might cause the concentration in the seed supply industry to increase.

It is possible not only to conceptualize a model where the private rate of return from joint private and public research is computed but also to examine the effect of private, public, and joint research on the structure of the producing sector itself. Why did the poultry industry become so concentrated? Was it because most of the research was done by the private sector so it could capture the rents and in the process become more concentrated? One justification for public research is that it should provide benefits to all producers. Public research could be structured to promote competition. Private research may lessen it. In the grape industry, for example, which is highly concentrated at least in terms of wine making of low- and medium-grade wines, the industry does not seem to be a large supporter of public research in the development of new varieties. Large firms may develop their own varieties for the express purpose of achieving a competitive edge. It appears that the extent to which research is done publicly, privately, and jointly significantly affects the structure of the producing sector.

Ex Post Evaluations and the Rate of Return

As the fine survey studies of Schuh and Tollini and of Norton and Davis point out, most ex post evaluations of agricultural research can be classified either as those that utilize concepts of producer's and consumer's surplus or those that employ production function estimates with research as an input variable (here the compute a commodity-specific rate of return or an aggregate rate of return.3/ Much of the concern of such measurements relates to the effect of technological change in terms of divergent (pivotal), divergent (proportional), convergent or parallel shifts in production and/or supply functions (Scobie). This research is perhaps most strongly supported by Ruttan, who has argued (p. 6):

> "A number of studies are now available within both traditions that estimate rate of return to national research systems rather than to individual commodities. There is also a tendency, since the important study by Schmitz and Seckler (1970) of tomato harvesting in California, to consider the distributional implications of agricultural research. A review of the body of literature summarized in Table 1 impresses one with the increasing degree of sophistication that authors of more recent studies have displayed in responding to the limitations of earlier studies. The effect of more careful model specification, more complete measurement of cost, greater caution in estimating benefits has, in my judgment, led to results that tend to under rather than overestimate returns to agricultural research."

Is the above view justified? In other words, are such rate-of-return measures robust? In addition, can such measures be employed to determine the appropriate level of public investment during the core-basic, semibasic, or applied stages of agricultural research? Partial answers to these questions are provided by problems which arise in appropriate measurement of research and development costs and knowledge output which have been adequately surveyed by Schuh and Tollini and thus will not concern us here. There are a number of other important concerns which raise serious doubts about the effective use of such rate-of-return measures. These concerns also provide the basis for designing operational ex ante frameworks for evaluating public investment during the various stages of agricultural research.

The first important issue relates to the distinguished stages of research and development. For illustrative purposes, consider the case of hybrid corn. How much of core-basic research costs should be attributed to the cost of developing hybrid corn? Were such costs considered by Griliches in his ex post evaluation of hybrid corn? No. For another example, should the amount of basic-core research cost in mechanics be attributed to the tomato harvester?

activities, the exact contribution is indeed difficult to measure. Moreover, how should the costs associated with unsuccessful semibasic and applied research that are pursued in conjunction with successful efforts be properly accounted?

Actual research and development activities take place in a portfolio context with many lines of activities pursued. Such a portfolio approach involves an explicit recognition not only of expected returns but also the variability of such returns. In an ex post context, glaring examples of successful research and development of the public sector are only a portion of the total story. There are also unsuccessful efforts whose variability may, in an ex ante sense, be larger or smaller than the variability attributed to the successful effort. Such considerations are simply not reflected by currently available ex post evaluations. In fact, none of the studies surveyed in Ruttan, Schuh and Tollini, Scobie, or Norton and Davis report reliability measures or standard errors associated with the estimated rate of return.4/ What this means is that the information that has been generated from ex post evaluations is of little real value to public decisionmakers in their portfolio choices. Even though analytical measures of reliability statistics cannot be derived, numerical measures could be used to compute approximate standard errors. Since available empirical evidence strongly suggests that there is risk aversion on the part of public research decisionmakers, what does a commodity-specific rate of return of 120% mean when unsuccessful research and development activities are not considered and the standard error associated with this high mean rate of return is three to four times as large?5/

Another important set of issues relates to the general equilibrium effects of public research in agriculture (Just, Schmitz, and Zilberman). Consider once again the case of hybrid corn. The discovery of hybrid corn affected directly the output market for corn, but it also had a significant impact on the markets of a number of other goods. Moreover, it had some effect on such input markets as fertilizer, labor, and machinery which benefited some groups and imposed costs on others. In addition, given the intermediate nature of the corn product, this development influenced the United States livestock sector. What effect did the development of hybrid corn have on the allocation of beef cattle between range land and feedlots? Did the development of hybrid corn have a significant effect on labor migration from the agricultural production sector to urban areas; and, if so, what were the benefits and costs of such migration? Such general equilibrium effects have important implications for the distribution of benefits and costs of successful aggregate rate of return. Implicitly, at best, such measures weigh each of the affected groups equally. Is this the correct normative weighting? Or would it be more useful for researchers to report the effects of alternative weightings across performance measures associated with each group in its desire to collapse a vector evaluation problem to a scaler?

Associated with the general equilibrium effects and questions of equity is the issue of the time period for evaluating the potential benefits from public research and development. Here a useful illustrative example is the case of Colombian rice research. This research resulted in high-yield varieties suitable for irrigated rice farms. The initial effect of this research (Scobie and Posada) was to benefit low-income consumers through price reductions, while rice producers (except some early adopters) incurred substantial losses. Scobie noted a second-round effect which was a substantial gain to industrial producers due to the reduced wage good price. With the passage of time, continuing research reduced cost even further; and according to Scobie the beneficiaries were the rice producers since the newer techniques resulted in the export of rice. Hence, only by a judicious selection of the time horizon for the evaluation of public research and development is it possible to capture the dynamic path resulting from both the direct and indirect effects of such research. In the case of Colombian rice research, this may involve the effect of cheap food on investment in the industrial sector, general growth, improved employment, and the like.

Related to the above issues is tracing the long-run effects of certain research discoveries that are most certainly not captured by current market evaluations often used in ex post evaluations. Some technological developments are sufficiently important to alter drastically the structure and nature of the economy. The measurement of the effects associated with these technologies using standard economic analysis can be seriously questioned. The effects of such technological developments influence drastically the set of relative prices, and thus we must design scenario studies to evaluate what would have happened without the introduction of such technological change. To illustrate these issues, suppose six years ago an effective substitute for oil had been captured. The ex post evaluation of this hypothetical discovery would have no doubt underestimated its social value. This is largely because it would have been difficult, if not impossible, to conceive of the dynamic path that has occurred without the development of such technology.

Specifically, all of the available ex post evaluations presume competitive markets in the private sector. There is a fair amount of empirical evidence for a number of components of the food and agricultural sector which strongly suggests that the imperfect or noncompetitive paradigm more closely approximates the behavior of such markets. More importantly, the introduction of technological change coming from the private sector, and in some instances from the public sector, may induce such noncompetitive market behavior.

Another set of issues related to the links between one R&D activity and another as well as the learning that occurs within each type of activity. In considering the ultimate effect of an R&D project, we must take into account the links between one research discovery and another. The entire process can be viewed in terms of links of a continuous chain. Certainly, some projects have more potential for further growth than others. This is particularly the case once we recognize the possibility of integrating the technological process with learning by doing. In other words, to account for the potential benefits of one possible R&D activity, we should take into account its associated learning-by-doing potential. For example, consider the introduction of hothouses where intensive agriculture can be employed under controlled weather conditions. The introduction of this technology resulted in a host of complementary research and development activities that tended to intensify the utilization of available space and led to such promising techniques as hydroponics. To be sure, these new developments are in their early stages, but their potential for further growth through learning by doing is obvious.

To summarize the above discussion, the obvious conclusion is that we as researchers should begin to move away from ex post evaluations which are based entirely upon rate-of-return measures. Continued pursuit of such measures reveals a lack of creativity. Our focus should begin to concentrate on questions of appropriate vector evaluations of public research and development, concentrating on such issues as the appropriate weights reflecting equity and distributional concerns, the dimensionality of such vectors, and a host of concerns related to the proper measurement of shadow values. In the next section, we shall turn to these important issues.

Framework for Ex Ante Evaluation of Public Research

To motivate a new framework for the ex ante evaluation of public research and agriculture, consider the Green Revolution which was expressly institutions. Available evidence supports the view that modern varieties generally require more water and fertilizer than traditional varieties. Consumers, as well as input suppliers, can be expected to benefit from the successful completion of such research. In the case of producers, they may be better, the same, or worse off. Thus, can producers be expected to contribute to such types of research? However, since fertilizer companies gain, should they contribute funds for research of hybrids that are undertaken in the public sector? If not, they become essentially "free riders."

The above highly simplified example is suggestive of a framework that is needed to determine the level of public support for agricultural research. To operationalize this framework, we must have in mind a specific group of decisionmakers in the public sector. This group of decisionmakers might be simply the committee formed to recommend directions for agricultural research and support levels. Such a group was established by the 1977 Food and Agricultural Act in the form of the Joint Council on Food and Agricultural Sciences. From another vantage point, this act also led to the formation of the National Agriculture Research and Extension Users Advisory Board. Another organization for which this framework would prove useful is IR-6, a national and regional research planning body which coordinates, analyzes, and evaluates the performance of individual state agricultural experiment stations. Still another group is the Experiment Station Committee on Policy (ESCOP). Other decisionmakers for which this framework might prove valuable include regional and land-grant university experiment station directors. These are the types of policy-recommending or decisionmaking bodies we have in mind in the development of this framework.

The framework involves four evaluative stages. Briefly, in the first stage, a qualitative screening is performed to determine whether a particular research proposal should be conducted entirely in the public sector or by the private sector. The chief factors to be considered in this qualitative screening are those identified in Section 2. They include patentability, enforceability, potential economic life, technological versus pecuniary effects, ability to imitate, and the current structure of the industry or industries which will be affected by such research development.

The second evaluation stage is quantitative in nature and involves the use of multiattribute utility analysis (Keeney and Raiffa) to determine the appropriate vector evaluations of those research areas that should be pursued by the set of weights reflecting equity and distributional concerns across components of that vector, is determined. The outcome is an initial "incidence of burden" vector across various groups in the private sector as well as various public agencies that can be expected to support the public research proposal.

In the third stage, the implied willingness to payoff various groups that are positively affected by such public research is compared to revealed willingness to pay. The third stage involves a set of operational rules for the provision of public goods and the determination of "supporting coalitions" for public research.

Presuming that a supporting coalition is found, the fourth evaluation stage is concerned with the allocation of the available research budget across individual research teams and across time. This fourth stage offers the advantage of recognizing the experimental and learning roles that must take place in any research process.

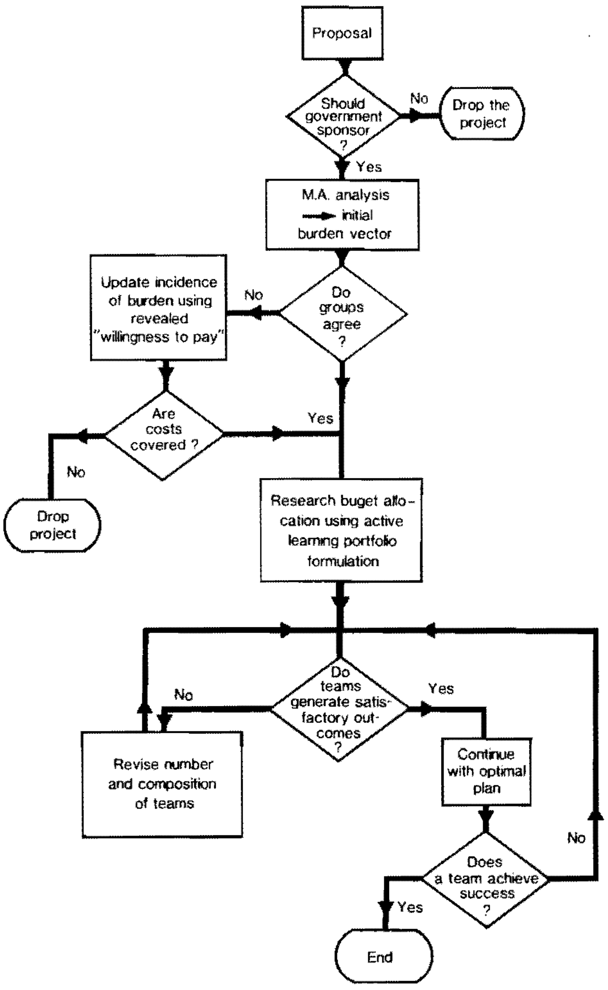
The various stages of the overall *ex ante* evaluation are represented in Figure 3. The initial step in the project evaluation procedure is the introduction of research proposals. Proposals can be introduced by anyone who requests public support. As usual, the proposal should include, at a minimum, a specification of a research project and the funding level.

The first decision to be made is whether the "public sector" should participate in the project. To answer this question, one has to determine whether there are incentives for this project to be undertaken by the private sector--more specifically, whether (1) the potential outcomes of the suggested project are patentable; (2) the patent is enforceable; (3) the outcomes have short economic life; (4) they are not easily imitated; and (5) the pecuniary effects of introducing them are desirable to the innovator. If the answer to all these questions is positive, the public decisionmaking body has to consider whether the undertaking of such a project by the private sector may have undesirable effects on the structure of the relevant industries. If that is not the case, the first-stage qualitative screening evaluation of the project terminates here, and its support is left to the private sector.

It should be noted that public research is not advocated in every instance in which private research may result in increased concentration. In some situations, the nature of the new technology, particularly its return to scale properties, along with the nature of the relevant output markets (degree of demand elasticity) may

of producers. Under these circumstances, undertaking such research in the public sector and ultimately releasing the successful completion of such research to the private sector will not

Figure 3. Flow Diagram for *Ex Ante* Evaluation of Public Research Projects



effectively alter the tendency toward such concentration. This, of course, suggests that such research need not be undertaken by the public sector. Thus, under the noncompetitive criterion, only if specific circumstances strongly suggest that public research can actually improve the industry structure should it be pursued.

iaries that should support the project may include individuals or groups in the private sector (corporations, farmer's organizations, etc.) as well as agencies of state and local governments. To determine the initial incidence of burden, the potential benefits for every group must be estimated and a set of weights associated with the welfare of each group must be derived. These weights can be captured using multiattribute utility analysis techniques introduced by Keeney and Raiffa. In their prescriptive paradigm, the central aspects of choosing policies when faced with multiple objectives are how to define an appropriate measure of each objective and how to resolve conflicts among objectives. They enforce comparability among alternative objectives in terms of a cardinal measure of their contribution to utility. The resulting scalar measure has been defined as a multiattribute utility function. Construction of such functions involves (1) structuring the objectives; (2) defining performance measures or attributes for each objective; (3) assessing univariate utility functions over each attribute; (4) determining the independence relationships among various attributes, i.e., preferential, utility, or additive independence; (5) specifying the functional form of the multiattribute utility function; and (6) measuring the scaling constants or weights associated with various attributes. Additive independence results in an additive multiattribute utility function, while preferential independence and utility independence result in a multiplicative multiattribute utility function. The critical problems in the application of this prescriptive approach revolve around consistent assessment of the univariate utility functions and the determination of the independence relationships among attributes. Considerable progress has been made on both these fronts; and, as the work of Keeney and Raiffa clearly demonstrates, the approach is operational.

At this juncture, we are faced with provisions of a public good problem. The multiattribute utility approach, along with some sound economic analysis, can be used to capture the benefit for group i (B_i), and the initial incidence of burden can be determined from

$$(1) \quad \text{Max EU } (B_1 - c_1, B_2 - c_2, \ldots, B_n - c\ )$$

subject to

$$(2) \quad \sum_{i=1}^{n} c_i = C$$

$$(3) \quad EU_i\ (B_i) \geq U_i(c_i) \qquad \text{for all } i = 1, n$$

where c is the total cost of the project, c_i utility function, and E is the expectation operation. When research administrators and all groups are risk neutral, (3) is nonbinding, and U(·) is additive and linear, then the incidence of burden becomes

$$(4) \quad c_i = \frac{\lambda_i\ \bar{B}_i}{\sum_{i=1} \bar{B}_i\ \lambda_i}\ C$$

where λ_i is the reciprocal of the weight assigned to group i and $\bar{B}_i$ is the mean of B_i. Neglecting transaction costs, once a set of c_i's is determined, the public research agency will ask each group, public or private, to pay their respective c_i shares in financing the project. If all groups support these requests, the project proposal is funded, and we proceed to the fourth stage. If the funds for the project cannot be raised in accordance with the initial incidence of burden, one possible approach is for the public agency to revise the incidence of burden using a revealed willingness-to-pay mechanism; namely, the agency will allow groups that are interested in the project to assume any additional burden they might wish to cover the deficit caused by lack of response from other groups. The project will then proceed if this second attempt results in the necessary funds; otherwise, the project will be discarded. It has been formally proved that this project selection procedure has some very desirable properties, namely, the selected project meets both the Kaldor-Hicks welfare criteria and the willingness-to-pay welfare criteria. These results have been formally proved by Dorfman.

Given the third-stage results in a research project budget, C, the fourth stage proceeds by addressing a decision problem that is indeed similar to a number of ex ante evaluation models, principally the Atkinson and Bobis model surveyed by Schuh and Tollini. In this fourth evaluation framework, there are large numbers of possible research teams (individual experiment stations) that could be supported. Each research team is presumed to have given endowments of manpower and equipment. There is an underlying probability distribution of success which is fixed but unknown. This probability refers to the success of a specific team and not to the success of the entire project. The success of the project, of course, is achieved when at least one team is successful. Given a prior probability of success, a specified planning horizon, and a specific criterion or reward function (based on the measurements in the second evaluation stage), an adaptive control portfolio formulation is employed to determine the optimal number of teams along with their associated budget allocations during each period of the

The approach has been developed in a recent working paper by Rausser, Yassour, and Zilberman. This work is an extension of the excellent Weitzman treatment of the optimal search for the best alternative.

To make the implementation of the above framework more concrete, we briefly consider here the case of the tomato harvester in technological development in California. As noted in a brief description of historical events in Table 2, serious research began on the development of the tomato harvester in the early 1940s. Even though machines existed to harvest other crops, such as small grains, potatoes, sugar beets, and cotton, tomatoes were too easily bruised by mechanical devices and, in addition, ripened at various times; thus, a concurrent program for biological redesign of tomatoes was necessary.6/

The need for complementary search of both a biological and a chemical nature in the case of tomatoes made necessary the effective coordination of such research. This coordinating role was assumed by the California Experiment Station. As the director of the University of California Experiment Station remarked in 1965:

> "We must recognize that machines will never be completely developed to work under the cultural practices now followed, or with the varieties of fruits and vegetables as we now know them.
>
> This is the great advantage the University has: engineers have the opportunity to work in cooperation with biologists such as plant breeders, pathologists, biochemists, irrigationists, and soil scientists to create a harvesting machine and with it a harvestable crop" [C. F. Kelly, quoted in the California Tomato Grower, Vol. 8, No. 10 (1965), p. 11].

As Table 2 suggests and the above observation reveals, the University of California over a period of more than 20 years, through a combination of engineering and horticultural research, was able to develop jointly both the machine harvester and the tomato plant to make this machine feasible. A few years after the harvesting of tomatoes had been fully mechanized and as the unionization of farmworkers created upward pressures on wages, new technological innovations were introduced to sort tomatoes electronically in the field, further reducing labor needs, changing the nature of the labor process, and fomenting greater economies of scale.

stage, the research proposal suggested by A. M. Jongeneel to Professor Hanna would certainly pass the set of criteria outlined for the first stage of the evaluative framework. Disregarding complementarity between the biological research and the development of the tomato harvester itself, the research begun by Professor Coby Lorenson would not be justified in accordance with the same list of criteria. The development of such technology is certainly patentable, and the patents are enforceable. However, due to the complementary nature of this research, the corresponding biological research which is justified in the public domain and observations on the noncompetitive structure of the California tomato industry, a case can be made for the research on the mechanical development of the harvester to take place in the public sector.7/ To be sure, at a minimum, research on the mechanical harvester could be accomplished by the university on a contract basis and still be effectively coordinated with the needed biological activities by the research administration of the experiment station.

The second stage of the evaluative framework, the required multiattribute utility analysis, makes it necessary to identify all potential gainers and losers from the development of the complementary biological and mechanical research. This involved identifying all groups potentially affected by such research by defining quantitative (performance) measures which correspond to objectives in the multiattribute utility analysis. This requires the development of performance measures for the major input suppliers (a handful of banks, seed, machinery, and chemical companies); processors of which there are approximately 20, with the largest being Hunt-Wesson; several grower cooperatives; larger landowners with land qualities suitable for growing tomatoes (these owners would certainly benefit from improved rental prices and their comparative low transaction costs in rental markets); the Tomato Growers Association; displaced domestic labor; and possibly other states which grow tomatoes. The potential benefits to the last group are highly questionable due, first, to the size of farms in states which grew tomatoes in the early 1940s and, second, to the fact that weather conditions in these states are far more variable than in California; thus, the uniform ripening that is crucial for mechanical harvests becomes a less likely outcome. It should have been possible to draw this inference in the early 1940s, but some degree of uncertainty would have been reflected in the multiattribute utility analysis.8/ In the case of the labor component, two quantitative performance measures could be justified. The first would recognize the unemployment or displacement effect and the second

World War II	Labor shortage creates impetus for tomato harvester.
1941-42	Conveyor machine developed in Pennsylvania.
1942	A. M. Jongennel, a California tomato grower, suggests to G. C. Hanna that the university develop a tomato plant that could be harvested by machine (Rasmussen, p. 534).
1943	Professor Hanna at the University of California begins research for tomato plants with desirable properties. "It was also reported in 1943 that a blacksmith in Holt, California, was building a tomato picker for a canning firm in Stockton" (Rasmussen, pp. 533 and 534).
Late 1940s	Pear-shaped tomato plant which ripens at same point in time and is adaptable to machine harvest is released.
1949	Professor Coby Lorensen begins work on the tomato harvester at the University of California, Davis.
1951-52	Tomato growers in California experiment with conveyer systems.
1956	California Tomato Growers Association grants funds to the University of California for work on the tomato harvester.
1958	Michigan State University team constructs a tomato harvester; University of Florida team develops conveyer belt machine; and Food Machinery Corporation and H.D. Hume Company fund work on a tomato harvester at Purdue University.
1959	University of California successfully completes the development of the tomato harvester. "The University of California then patented the machine and licensed the Blackwelder Manufacturing Company to undertake its commercial manufacture" (Rasmussen, p. 536). The Blackwelder Manufacturing Company had been working closely with the University in the development of the tomato harvester. The California Tomato Growers Association attempts to assume the role of a bargaining cooperative, but canners are able to effectively divide growers; and two years later the Association returns to its previous role of providing services and information to member growers.
1960	Blackwelder builds 15 harvesters. Five types of machines are tested, and 1,200 tons of pear-shaped tomatoes are harvested by machine. "On September 1, 1960, 2,000 tomato growers, processors, bankers, etc., gathered at the Heringer ranch south of Courtland to witness a demonstration of the University of California Blackwelder machine" [California Tomato Grower, Vol. 8, No. 9 (October, 1965), p. 5].
1961	Mechanical tomato harvester first used commercially. There are 25 University of California Blackwelder machines in grower's hands; .5% of the California processing tomatoes are harvested mechanically; and 6 other firms test machines, including 2 large farm machinery corporations, Hume and Food Machinery Corporations. Professor Hanna released the F-145 tomatoes at the University of California. A strain selected from this variety is basic to the mechanization of tomatoes in California.
1964	Public Law 78 (bracero program) is terminated.
1965	Tomato growers in California obtain special dispensation to import Mexican workers for harvest. The first major action of the National Farm Workers Association, later to become the United Farm Workers, assumes the form of a grape strike in Delano.
1967	Federal minimum wage legislation extended to agricultural workers.

1970	Adoption of mechanical tomato harvester completed in California. Attempt by California Tomato Growers Association to implement a government marketing order to control the supply of processing tomatoes fails.
1974	California Tomato Growers Association is recognized by processors as grower bargaining association for negotiating forward pricing contracts.
1975	California law (Agricultural Labor Relations Act) grants agricultural employees the right to form unions and bargain collectively. Electronic sorter (which reduces the necessary labor on the harvester from about 15 to 5) used commercially in tomato harvest (on 30 machines).
1976	California law insuring unemployment benefits for agricultural workers. United Farm Workers attempt to organize labor in the harvesting of tomatoes. Mass adoption of electronic sorter eliminates approximately 5,000 workers from the harvesting of tomatoes.

Source: Adapted from Alain de Janvry, E. Phillip LeVeen, and David Runsten, "Mechanization in California Agriculture: The Case of Canning Tomatoes."

would recognize the skill or substitution effect. These two effects both occurred initially as a result of the adoption of the tomato harvester and later as a result of the adoption of the electronic sorter. For the remaining groups, a number of decompositions in accordance with wealth and endowments could have been easily justified.

Given the above admittedly vague description of structuring the performance measures, the multiattribute utility analysis would proceed by identifying a public decisionmaking body. For this body, the univariate utility functions over each quantitative performance measure would be assessed, and the nature of independence among the various quantitative measures could be determined. Specification of a functional form and derivation of the "scaling constants" would allow preference weights, λ_i, to be computed.

The third stage of the evaluative framework, the incidence of burden among the various beneficiary groups and the compensation of displaced labor, is determined. To compute this burden, all we require is the measure, λ_i; the quantitative performance measure, B_i; and the total proposed cost of the complementary research on development of both an appropriate tomato plant and the mechanical harvester. To be sure, this is no simple matter. Nevertheless, it is operationally feasible; and the transaction cost of implementing this third stage in case of all beneficiary groups by the coordinator, the University of California, could be easily incorporated into the total cost of the research project C. To compensate all future potential labor would, of course, be prohibitive. Various means, however, could have been developed to place such compensating amounts in a public fund for facilitating the social transformation of the current generation of tomato harvest workers to other gainful employment. Such funds might be allocated for the purpose of temporary welfare, retraining, and the general augmentation of human capital.

The evaluative framework envisaged here most certainly placed greater demands upon the university in its coordinating role. Nevertheless, it is our view that the benefits of implementing the evaluative framework far outweigh its cost from a social perspective. It is certainly superior to imposing upon the private sector a nonzero sum game recently advocated by Secretary of Agriculture, Bob Bergland. Moreover, it is superior to allowing the university to pursue the coordinating role it actually undertook for the California tomato industry with only small, marginal research funding contributions from the principal beneficiary groups. A nonzero sum game resulted in which the distribution of benefits accrued to a few select groups, with some rather substantial costs imposed on the less favored.

The implementation of the fourth stage of the evaluative framework with the illustrative example under consideration brings no surprise. This stage is largely technical and, in the context of the complementary biological and mechanical research, would have required the evaluation of one or more research teams for both desirable tomato plants and the tomato harvester. Of course, it would also have involved recognizing timing and sequential development of the have been saved as a result of implementing this fourth evaluative stage.

This illustrative example, along with our observations in Section 3, has some rather direct implications for further *ex post* evaluations of public research in agriculture. That is, instead of pursuing aggregate rate-of-return measures, agricultural economists should seriously consider pursuing the four stages outlined here for *ex ante* evaluations. In the context of the California tomato harvester, this would necessitate pursuing the quantifications required by the multiattribute utility analysis on a historical basis. Various hypothetical univariate utility functions, independence relationships, and preference weights could be investigated. This would allow us to capture the robustness of alternative multivariate utility functions on the derivation of the incidence of burden vectors. It would be interesting to quantify the transaction costs associated with implementing the third stage in an *ex post* setting. We are in the process of beginning this research agenda for the case of the California tomato harvester.

The above framework can adequately deal with one of the dominant explanations for underinvestment in agricultural research. This explanation relates to geographical spillovers resulting from research undertaken by a particular, spatially defined institution (Latimer and Paarlberg; Schultz). This view argues that positive external effects of research accrue partially to other states and nations; such benefits are only partially captured by the institution that incurs the research cost. Schultz has referred to this phenomenon as the "obsolete organization of public finance" in the United States. In the case of experiment stations, state funds cover the bulk of the agricultural research cost, while returns accrue to other states. Boyce and Evenson use this observation to explain why developed countries have found the expansion of their extension systems more attractive than investing in agricultural research. This has motivated Evenson and Binswanger to recommend international cooperation in agricultural research in order to provide the appropriate incentives and signals for a more nearly optimal level of public investment. These issues are dealt with in the above framework by the second and third stages of evaluation. In the second stage, the benefits accruing to other states or, in a national context, to other countries are determined along with associated preference weights for these benefits. This allows the computation of the incidence of burden, and the third stage proceeds to determine whether an effective

In the context of various stages of research, the suggested framework is certainly applicable to the evaluation of applied research. Since the semibasic research stage is also targeted toward potential applied areas, the proposed framework also seems appropriate in this instance. However, it should be obvious that a fair degree of insight and wisdom would be required in implementing the proposed framework for evaluation of semibasic research.

In the case of core-basic research, the four-stage evaluative framework would be difficult, if not impossible, to implement. Here the observation of Schuh and Tollini that "an overemphasis on evaluating research and assessing and monitoring research can stifle activity and destroy research entrepreneurship" is particularly applicable. At best, what can be suggested for evaluation of core-basic research is a framework based on Simon's notion of bounded rationality. In this setting, bounded rationality might assume the form of satisficing goals measured in terms of what a society weights favorably. National implementation of this framework might be represented in terms of a lexicographic ordering across various social indicators.9/ One social indicator might be simply the amount of public funds allocated to core-basic research and the development of human capital. If a satisficing level of this indicator is reached, the allocation of this budget could be made simply in accordance with its potential effects on options available in the future. The desirable outcome would be the maximization of the number of such options. Obviously, economists do not have an inside track on the evaluation of such alternatives; a multidisciplinary research evaluation team seems in order.

Positive Analysis of Public Research in Agriculture

The framework for *ex ante* evaluation of public research outlined in the previous section was developed in the context of normative analysis: it identified a set of stages that should be followed in order to achieve an optimal solution. Once this is established, however, we need to understand the origins of divergencies between actual and optimum research solutions in order to identify the difficulties in eventually moving from the former to the latter. For this purpose, it is essential to unravel the social processes that determine the actual pattern of allocation of resources to public research. This calls on a theory of how the public sector operates in relation to the process of accumulation in the economic system and to the conflictive demands of civil society.

particular, the theory of collective action and interest politics (Olson, Downs); the theory of economic regulation and governmental intervention (Stigler, Peltzman); the theory of bureaucratic behavior (Lindblom); and the theory of the state (Jessop). Since we believe that it is important to raise the issues of special classes in relation to the public sector and of the degree of autonomy of the public sector with respect to both economic and political phenomena, we will rely here on the theory of the state developed in the body of thought of classical political economy. This approach also permits us to shed some new light on the old puzzle of explaining both the presumed global underinvestment in agricultural research and highly uneven investment of research funds among crops, regions, and types of technologies.

As previously noted, the dominant explanations of underinvestment are based on the existence of institutional externalities (Latimer and Paarlberg, Schultz) and also on the systematic ex ante underestimation of ex post benefit-cost ratios (Hirschmann).

Two additional interpretations derive from observing the role of interest politics in affecting the allocation of public monies to agricultural research. One consists in observing that the demand for technological innovations originated among producers has a small political basis. This demand is confined to the small minority which can derive Schumpeterian profits from being early innovators (Ruttan). The majority of producers is coerced into adopting the cost-reducing new techniques by treadmill mechanisms that are effective through the product market or the land market according to the elasticity of demand (Owen, de Janvry). In interest politics, the majority of farmers (with corresponding large political bases) consequently plays only a passive role on the issue of technology but effectively can be mobilized on other policy issues, such as the implementation of commodity price programs.

On the demand side, consumer support for production research is similarly weak and discontinuous in spite of the fact that consumers are presumed to capture the bulk of gains from research. This is due to the small individual gains of consumer advocacy (Olson) and to the existence of other policy approaches, such as price controls and food subsidy programs, which have more immediate and more certain payoffs. As a result, Ruttan (p. 12) observes that consumer support for production research "tends to emerge during periods of sharply rising prices and to be rapidly dissipated during periods of

investment in agricultural research to an insufficient supply of research skills and to a deficit of administrative capabilities in research institutions (Evenson). Insufficient investment in the production of human capital is seen to result in underinvestment in research; this is particularly so in the less-developed countries.

While each of these interpretations may have explanatory power in particular situations, it is our feeling that the determinants of the presumed underinvestment in agricultural research also have to be sought in the broader context of political economy and, in particular, in an understanding of the role of the state (the public sector) in both economic and political life. We consequently attempt to bridge the gap between the theory of the state and the theory of induced innovations in order to outline elements of a political economy of induced innovations that shed some new light on the question of the presumed underinvestment in research.

It is useful for this purpose to contrast three processes through which agricultural technology is being produced. One is via the private sector and, in particular, agribusiness firms. The second is via the public sector acting "from above" in an active and coordinated fashion. And the third is via the public sector responding to pressures "from below" in a relatively passive and decentralized fashion. Each of these processes is activated by different social mechanisms and has specific characteristics in terms of rate and bias of technological change as well as in terms of underinvestment of research resources.

It is clear that private semibasic and applied research in agriculture has been extremely important but, as we saw in Section 2, is confined to specific types of technological developments. From a social standpoint, underinvestment of private funds is the principal reason which has been given for assigning an important role to public sector research. Clearly, private research and development is motivated by profit seeking and will, consequently, tend to occur whenever profit and risk conditions create comparatively attractive investment opportunities. Underinvestment of private funds from a private standpoint is not an issue here, but failure of the state to provide the complementary package of public research will create serious biases in technological paths.

Since mechanical and chemical innovations tend to be more easily patentable than biological tion swept through much of Third World agriculture before the Green Revolution;10/ and the mechanical tomato harvester had been successfully manufactured before release of an adequate tomato plant. Similarly, chemical control of pests and diseases still tends to dominate biological and genetic control (van den Bosch). This observation is not meant to invalidate the theory of induced innovations, but rather, to say that response to price signals occurs via different social processes--in this case, private versus public--and that an imbalance between these processes can seriously impair the relationship between factor price ratios and relative factor intensities of new technologies.

The state, as a set of public institutions, fundamentally reacts in an active and coordinated manner to situations of actual or anticipated crises. These crises can be either economic or political as they originate in contradictions that emerge either in the process of capital accumulation or that of the reproduction of social class positions. Economic crises may include food price inflation, deficits in the balance of payments, upward pressures on wages, falling production due to diseases or erosion, etc. Political crises occur in the form of consumer demands for cheaper food, organized labor pressures for better employment conditions, and the like.

The state will react to a situation of crisis and implement a set of reforms designed to counteract the effects of the contradictions that define the crisis if the dominant social class has enough class consciousness and instrumental power over the state. But these reforms can also be designed and implemented without this active class participation if we admit that the state and its managers possess a certain degree of autonomy relative to the particular--often contradictory--demands of interest groups. It is precisely this relative autonomy that legitimizes the state as a public institution that is seen to exist above society and allows it to intervene in an attempt at reconciling conflictive demands. It is also this relative autonomy that empowers the state with a broader vision of the neeeds of society than that possessed by the dominant class. Yet, this autonomy is only relative since the power and perpetuation of the state and its managers are conditional upon continued capital accumulation and reproduction of class positions. As a result, the state, in spite of a certain degree of autonomy, needs to be motivated by the type of interests that would emerge out of dominant class consciousness and instrumental control. The scope of action of the state is, however, severely constrained by three types of limits: its fiscal capacity, its own legitimacy as an institution, and its administrative capability (O'Connor).

is: when will a technological solution be sought versus other solutions such as price, labor, credit, or fiscal policies? And it is because a technological solution is often not sought, in spite of potentially favorable *ex ante* economic calculus, that underinvestment in research may occur for a variety of reasons. First, precisely because during periods of crisis the state is actively mobilized, there tends to then exist a discrepancy between economic calculus and political time. Since the technological solution is relatively long term and costly involving elements of randomness, it is often discarded for other instruments. Second, the state tends to run into limits precisely during periods of crisis. Fiscal revenues are then particularly scarce and inflation constraints binding, the legitimacy of the state is more open to challenge, and the administrative capacity is spread thin over many fronts. Thus, the state is, in a sense, least capable when most needed. This also limits the capacity of the state to call on technological solutions.

In spite of this, it is through the role of the active and coordinated state that some of the greatest technological achievements have occurred. Examples include research on hybrid corn in the United States, dwarf wheat in Mexico, and irrigated rice in Colombia. Yet, because of the crisis nature of its interventions, active mobilization of the state on the issue of technology has been generally uneven over time and constrained by the crisis itself. This we take to be a potentially important explanation of the presumed systematic underinvestment in agricultural research.

The polar opposite of the active and coordinated state intervening from above is the decentralized state responding to demands from interest groups in a market-like fashion. This is particularly typical of the use of existing public institutions (themselves usually created from above as part of crisis response) that tend to be appropriated by particular social groups, especially through the formation of guild-like organizations. The most blatant mechanism through which this occurs is when private interest groups make research grants to public institutions. The multiplier effect obtained is usually large as small amounts of private funds that cover marginal research expenditures powerfully affect the definition of research and divert toward this end large amounts of public funds.

The flow of research generated through this form of state activity tends to be highly uneven among crops, regions, and types of technologies (Pineiro, Trigo, and Fiorentino). It is strongly conditioned by the existence of powerful interest public research. In the third world, export crops such as coffee, cotton, palm oil, and rubber have also benefited from large research appropriations by contrast to most staple food crops. In many cases and in contrast to the Schumpeterian and Marshallian bases of the theories on induced innovations and the technological treadmill, the active social agents have not been producers but organized interests of the agribusiness (processors and input manufacturers), commercial, and financial sectors. This has been the case for research on mechanization of sugar beet and tomato harvesting where processors induced public sector response. This is also the case for the bulk of research on the chemical control of pests and diseases.

The limit of the state, especially its fiscal constraints, reinforces this market approach to public research as it intensifies the search by scientists and research administrators for private research monies and competitive grants. Since funds are principally obtained from private interest groups, the research conducted tends to be relatively short run and applied. Thus, in the control of pests and diseases, chemical control is more easily funded than biological control, and biological control more easily funded than genetic resistance.

Underinvestment in research in this third and most common process will tend to result from underrepresentation and lack of financial means for numerous interest groups. This is particularly evident for any research oriented at small farms and at rural labor and rural communities. Underinvestment also results from lack of coordination among branches of the public sector that generate or affect technological change. This is due to the fact that interest groups appropriation of public research capacity is only partial and fragmented. As a result, the more complex interdisciplinary and systems approaches to research will tend not to be funded under this approach. And coordination between technological and economic policies will also typically be lacking, jeopardizing effective diffusion of technological change.

This third social process of inducement of innovations appears to be increasingly important as the economy enters into post-Keynesian inflationary periods and fiscal crises. Clearly, tremendous technological achievements have been obtained under this approach; but they tend to be relatively short-run technological fixes resulting in sharply unequal patterns of technological development among crops, farms, regions, and technological options. The theory of induced innovations can, in this context, no longer serve to explain the generation of technology most powerful social groups in society (de Janvry, Gutman, Grabowski).

Footnotes

1/The remaining discussion draws heavily from the work of Hueth, Schmitz, and Cooper.

2/There are, of course, exceptions. For example, Peterson's analysis of poultry research calculated the social rate of return from both (joint) public and private research.

3/There are other major studies which do not fall into one of these two general categories. One group has been characterized by Norton and Davis as the "change in national income approach." An example of this type of analysis is provided in Tweeten and Hines. Still another group of studies has been characterized by Norton and Davis as nutritional impact investigations, and here the example frequently cited is Pinstrup-Andersen, Londono, and Hoover.

4/This is not entirely surprising since, analytically, it is not possible to compute in close form the reliability statistics for such measures due to the nonlinearities of the aggregate rate of return.

5/Ruttan has employed the portfolio analysis view to interpret public investments by state experiment stations in agricultural research.

6/The harvester under evaluation was developed to pick canning tomatoes. The harvester technology was feasible due to the short time elapsing between harvest and processing. In recent years a machine has been developed to harvest tomatoes for the fresh market, but this new phenomenon is not examined here.

7/For qualitative arguments supporting the view that the California tomato industry is noncompetitive, see de Janvry, LeVeen, and Runsten. For an econometric analysis of the noncompetitive structure of this industry, see Chern and Just.

8/Historical evidence has corroborated the importance of these few reasons in the form of a shift in production from other states to California as a result of California's adoption of the mechanical tomato harvester. In other states, the incentives to adopt the mechanical tomato harvester were severely tempered.

9/For an excellent treatment of social indicators and their measurements, see Fox.

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