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PRINCIPAL ISSUES IN THE EVALUATION OF PUBLIC RESEARCH IN AGRICULTURE

Gordon C. Rausser, Alain de Janvry,
Andrew Schmitz, and David Zilberman

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
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1. 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 demonstratable 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 the 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 in Section 2. 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.

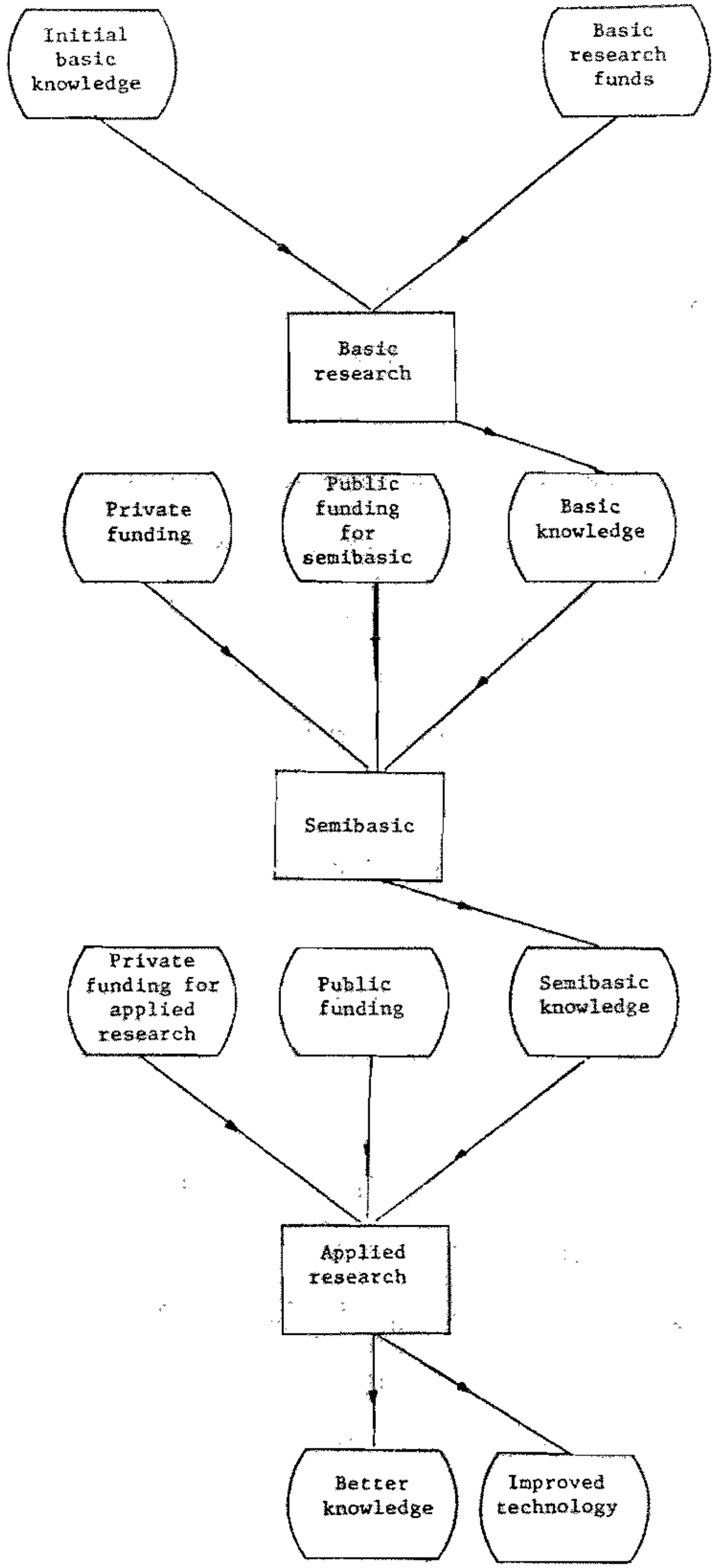

FIGURE 1. The Process of Research

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 and Lind), the distinction between public and private discount rates (Marglin, Rawls), and the magnitude of uncertainty and the economic life of generated knowledge. Other reasons for public support that are generally not recognized by analysts relate to the public sector's desire to foster and maintain a competitive structure within the agriculture and food sector. This basis 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 observations, 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 but also by the social relations of its diffusion, it is essential to go beyond the market theories of technological change. The market dominated paradigms are based largely on the 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 decision-makers, 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 govermental intervention, and the theory of endogenous govermental 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.

2. 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 decision making. Applied research results in either embodied or disembodied technological changes. Applied research can have two effects: technological, through the improvement of production functions, and pecuniary wealth redistributions due to price reevaluations that may occur from the 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,

TABLE 1

Research Activities Classified by Research Stage and Type

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	
Mechnical	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

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 semibasic 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 provide less incentive for private investments in research and development activities. Moreover, they note that, in the case of the commonly tested hypothesis that research and development activity increases more than proportionately with firm 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 innovators' 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 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]

To illustrate the importance of the noncompetitive criterion, we analyze the outcome of research activity using alternative rate-of-return measures for R&D activities. While the rate-of-return analysis is useful at this juncture for illustrative purposes, it will be argued in Section 3 that such measures are flawed and that their popular use as an ex post 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

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[1]The remaining discussion of Section 2 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.

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 directly to their investments versus the rate of return for the same benefits accruing to both their investments and public investments.

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 as well to public research activities. 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 less than the private rate (i.e., the private rate exceeds the social rate). This is demonstrated in Figure 2 where the net addition to the private sector in the new equilibrium 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 if 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.

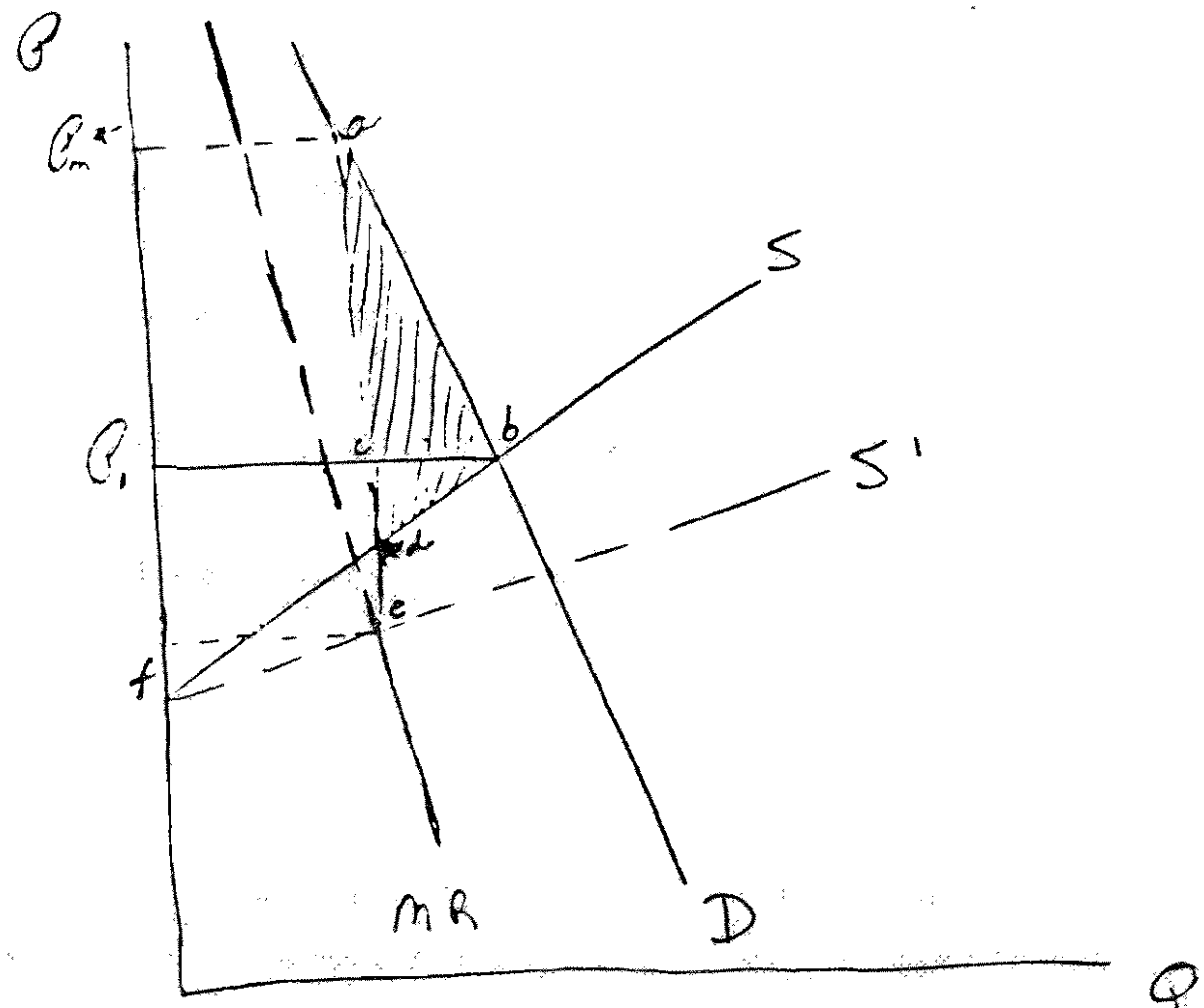

FIGURE 2. Monopoly Pricing Resulting From Technological Change.

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?

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 producers and hence their inability as a group to deal directly with public institutions, input suppliers provide the link between public institutions 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 concentated 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.

3. 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 concern is with estimating a marginal rate of return to research). For each of these two groups of studies, the ultimate purpose is to compute a commodity-specific rate of return or an aggregate rate of return.[1] 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 judgement, led to results that tend to under rather than overestimate return to agricultural research."

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[1]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.

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? While it is clear that the discovery of hybrid corn and the development of the tomato harvester have benefited from core and semibasic research 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.[1] What this means is that the information that has been generated from *ex post* evaluations is of little real value to public decision-makers 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 decision-makers, what does a commodity-specific rate of return of 120 percent 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?[2]

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

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[1]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 rates of return.

[2]Ruttan has employed the portfolio analysis view to interpret public investments by state experiment stations in agricultural research.

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 U. S. 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 research efforts, both across and within groups of the food and agricultural sector. Ex post evaluations have concentrated only on an aggregate rate of return. Implicitly, at best, such measures weight 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 results 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 economic 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 <u>ex post</u> 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 scenerio 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 <u>ex post</u> evaluation of this hypothetical discovery would have no doubt underestimated its social value. This is largely because it would have been indeed difficult, if not impossible, to conceive of the dynamic path that has occurred without the development of such technology.

Another issue neglected by the currently available rate-of-return studies is the question of market structure, conduct, and performance. 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 relates to the links between one research and development activity and another as well as the learning that occurs within each type of activity. In considering the ultimate effect of a research and development 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 research and development 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 hydrophonics. 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.

4. Framework for Ex Ante Evaluations 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 concerned with the development of seed varieties for the express purpose of increasing production. This research was carried out largely by public 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 decision-makers in the public sector. This group of decision-makers 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 decision-makers for which this framework might prove valuable include regional, state, and land-grant university experiment station directors. These are the types of policy recommending or decision-making 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 developments. 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 public sector. In this stage, the dimensionality of this vector, as well as the appropriate 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 pay of various groups that are positively affected by such public research is compared to revealed willingness to pay. This 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 decision-making 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 give rise to larger plants and a reduced number of producers. Under these circumstances, undertaking such research in the public sector and ultimately releasing the successful completion of such research to

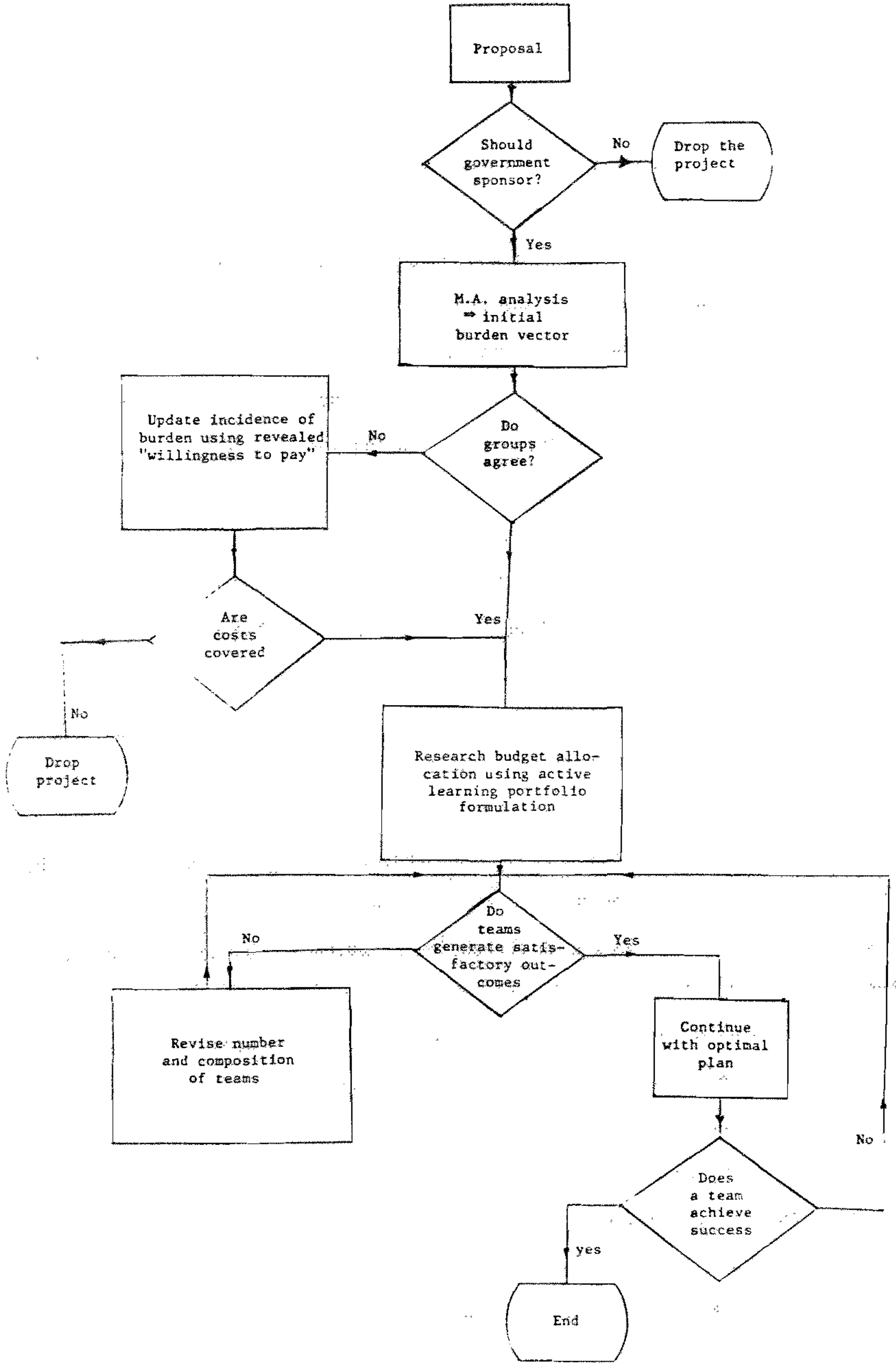

FIGURE 3. Flow Diagram for *Ex Ante* Evaluation of Public Research Projects

the private sector will not 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.

In cases where public participation is desirable, an incidence of burden among potential beneficiaries must be determined. The beneficiaries that should support the project may include individuals or groups in the private sector (corporations, farmers' 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) $$\text{Max } EU\,(B_1 - c_1,\ B_2 - c_2,\ \ldots,\ B_n - c_n)$$

subject to

(2) $$\sum_{i=1}^{n} c_i = C$$

(3) $$EU_i\,(B_i) \geq U_i(c_i) \qquad \text{for all } i = 1, n$$

where c is the total cost of the project, c_i denotes the cost burden to group i, U(•) represents the assessed multiattribute utility function, $U_i(\cdot)$ represents the (perceived) univariate 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) $$c_i = \frac{\lambda_i \bar{B}_i}{\sum\limits_{i=1} \bar{B}_i \lambda_i} C$$

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 planning horizon. This framework attempts to diversify across various teams in order to minimize a length of time taken to arrive at a successful outcome. 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 devises and, in addition, ripened at various times; thus, a concurrent program for biological redesign of tomatoes was necessary.[1]

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[1]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.

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 <u>California Tomato Grower</u>, 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 farm workers 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.

Blessed with the hindsight of Table 2, the implementation of the framework diagrammed in Figure 3 can now be examined. In the first 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 Lorensen would not be justified in accordance with the same list of criteria.

TABLE 2

Historical Events in the Development of the Tomato Harvester

Period	Historical Event
World War II	Labor shortage creates impetus for tomato havester.
1941-42	Conveyer 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 growers' hands; .5 percent 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.

Professer Hanna releases 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 the 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."

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.[1] 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

[1]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.

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 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.[1] 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 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 decision-making 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.

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[1]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.

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 places 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 surprises. 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 biological research vis-à-vis the mechanical research. Conceptually, both time and cost could 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 future 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, spacially 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 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 supporting coalition among countries or states can be isolated.

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.[1] 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.

5. 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

[1]For an excellent treatment of social indicators and their measurements, see Fox.

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.

There exist a number of alternative paradigms that can be used for this purpose, each of which approaches the problem from a different--not necessarily exclusive--angle. This includes, in 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 originating 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 relative price stability."

Finally, there are a number of explanations on the human capital side attributing underinvestment 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 agricuture has been extremely important but, as we saw in Section 2, is confined to specific types of technological developments. Underinvestment, from a social standpoint, 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 innovations, a technological path dominated by the private sector will tend to be heavily biased toward the former two. Thus, the tractor revolution swept through much of Third World agriculture before the Green Revolution;[1] 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.

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[1]For the supporting evidence on this observation, see Thirsk and Sanders.

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 needs 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).

In relation to the question of underinvestment in agricultural research, the key question--given a situation of actual or perceived crisis--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. And 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 groups that define the social power map. Thus, in the United States, commodities such as cotton and tobacco have received privileged support from 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 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 group 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 in relation to the relative social scarcity of factors of production but is confined to explaining the response to the factor endowments of the most powerful social groups in society (de Janvry, Gutman, Grabowski).

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