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The last decade has been characterized by a growing lack of confidence in research decision making processes. In the United States the agricultural research establishment has been viewed as unresponsive to environmental, distributional and humanitarian concerns (Berry; Hadwiger; Mayer and Mayer; Meier). New clientele groups have attempted to move concerns such as nutrition, rural development, environmental impact, soil conservation and the problems of hired workers higher on the research agenda (Paarlberg).

One result has been an effort to design and implement more responsive allocation mechanisms. Within the U.S. Department of Agriculture this took the form in the late 1960s of attempting to adapt the program, planning and budgeting system (PPBS) for research decision making (Puterbaugh). A number of the state agricultural experiment stations experimented with attempts to develop more responsive research resource allocation systems (Fishel; Shumway). The United Kingdom has attempted to apply the customer-contractor principle to research sponsored by the Agricultural Research Council (Ulbricht). Brazil has established an autonomous public corporation to manage its commodity-oriented national research programs and to support the several state research programs (Pastore and Alves). In 1972 the Agricultural Research Service (ARS) was reorganized to facilitate greater central direction of research effort within the USDA agricultural research system. More recently the federal program of institutional support for research at the state agricultural experiment stations has been supplemented by a new program of competitive grants in support of individual projects (table 1).

In this paper we attempt to analyze some of the efficiency implications of two alternative research funding systems: (a) A system in which funds are made available to support the research program of a particular research institution. We refer to this as the institutional research support (IR) system. The institutional research (IR) support was the traditional instrument employed to support federal and state mission-oriented research in the fields of defense, agriculture, natural resource exploration, industrial standards and related areas prior to World War II (Dupree). (b) A system in which support is provided through project grants to individual scientists or research teams. We will refer to this as the project research grant (PR) system. The project research grant (PR) mechanism emerged as a major instrument for linking academic research with mission-oriented federal agencies in the late 1940s and early 1950s (Stein).

The competitive grant program of the National Science Foundation, in which grant requests are received from individual scientists or research teams and evaluated by peer panels, is a prototype of the project research system. The program of federal support for agricultural research under the Hatch Act, in which funds are allocated to

Table 1. Funds Appropriated for Agricultural Research under Cooperative Research Programs of the USDA Science and Education Administration[a]

	1977 Amount	1977 Percent	1978 Amount	1978 Percent	1979 Amount	1979 Percent	1980 Budget Amount	1980 Budget Percent
	($000,000)	%	($000,000)	%	($000,000)	%	($000,000)	%
Cooperative Research								
Hatch Act[b]	98.0	76.0	109.1	69.0	109.1	62.6	109.1	61.2
- Regular	73.1	56.7	81.1	51.3	81.1	46.5	--	--
- Regional	21.7	16.8	24.5	15.5	24.5	14.0	--	--
McIntire-Stennis[c]	8.2	6.4	9.5	6.0	9.5	5.4	9.5	5.3
1890 Colleges and Tuskegee Institute	13.4	10.4	14.2	9.0	16.4	9.4	16.4	9.2
Special Research Grants	6.3	4.9	7.2	4.6	16.2	9.3	11.6	6.5
Competitive Research Grants	--	--	15.0	9.5	15.0	8.6	30.0	16.8
Animal Health and Disease	--	--	--	--	5.0	2.9	--	--
Rural Development	1.5	1.2	1.5	0.9	1.5	0.9	--	--
Federal Administration	1.7	1.3	1.7	1.1	1.7	9.7	1.8	1.0
Total	129.0	100.0	158.2	100.0	174.4	100.0	178.3	100.0

[a]Prior to 1978 the Cooperative State Research Service (CSRS).

[b]Total includes regular and regional funds distributed to states plus federal administration and penalty mail.

[c]Cooperative forestry research.

Source: USDA, SEA and CSRS memoranda to state agricultural experiment station directors.

state agricultural experiment stations on a formula basis, is a prototype of the institutional research system.[1] Institutional support is also provided in the major research-oriented universities through reduced teaching loads (Keyfitz). Many funding agencies employ both methods in their research support activities. The U.S. Agency for International Development (US/AID) provides institutional grants in support of the research programs of the international agricultural research centers which are part of the Consultative Group on International Agricultural Research (CGIAR) system. It also operates a competitive project research grant program. The Ford Foundation has provided institutional support for the research program of Resources for the Future since the early 1950s. It has also made institutional grants to the Social Science Research Council to enable the Council to operate the Foreign Area Fellowship Program--a program of project research grants. The state agricultural experiment stations employ a project system as an instrument in managing their institutionally funded research programs.

The traditional argument for an institutional research (IR) system is that it provides the continuity of program support that is needed for the long-term commitment of professional resources and facilities to problems of major scientific, technical or social significance. In agriculture, for example, it is argued that the long-term commitment of professional resources to particular institutions--such as those that led to the development of hybrid corn, rust resistance in wheat, vaccine to control Marek's disease in poultry, or improvement in the yield of rice in the tropics--would be unlikely to occur under a project research system.

The argument that is typically made for support of research through a project research grant system is that it creates a market-like environment that attracts the most creative scientific talent to priority areas of scientific or technological endeavor. Arguments in favor of the PR system are also frequently linked with arguments in favor of a peer review system for allocating resources among competing project proposals.

There has been considerable discussion in recent literature of the equity considerations involved in project research grant programs (Bowers; Gustafson; Cole, et al.). The system has been criticized for inequity among institutions and individuals--for unduly favoring established research scientists and institutions. The general conclusion of the several evaluation studies is that allegations of bias in the grant-making system cannot be sustained. The efficiency implications of the project research grant system have, however, received relatively little attention. Bernard R. Stein has argued that a project grant mechanism that is not closely linked with mission-oriented institutions has led to the substitution of scientific progress for the achievement of tangible technical ends as a measure of public accountability. The system has also been criticized in a recent Science editorial for diverting excessive scientific effort to grant preparation, evaluation and administration (Leopold).

The sources of funds available to U.S. state agricultural experiment stations have consisted primarily of federal funds appropriated to the states on a formula basis and of funds appropriated for agricultural research by state legislative bodies (table 1). Although federal "formula" funds are granted to the state on a matching basis, in recent years most states have supported agricultural research at a level that substantially exceeds the federal matching requirements. In addition to federal and state funds, many state agricultural experiment stations also obtain substantial contract and grant support from private industry, private foundations, the U.S. Department of Agriculture and from other federal and state sources. The contract and grant support from other federal agencies and other sources has tended to increase slightly more rapidly than the traditional sources of funds.

The most interesting new development in the funding of agricultural research has been the establishment by Congress of a federally funded competitive research grant program open to all scientists to be administered by the Cooperative State Research Service (since January 24, 1978, the Cooperative Research Unit of the U.S.D.A. Science and Education Administration).[2] The FY 1978 appropriation act made a total of $15 million available for competitive research grants. The executive budget for FY 1979 proposed that the competitive grants program be increased by an additional $15 million. This was to be offset by a reduction of approximately $12 million in Hatch Act formula funding plus reductions of approximately $2.0 million in special research grants and $1.5 million in rural development research.[3] The 1979 appropriations act that was finally passed by the Congress restored the cuts in the Hatch Act funds that had been recommended by the administration and continued the competitive research grant program at the $15.0 million level. The executive budget for FY 1980 continues Hatch funding at the FY 1979 level and proposes an increase in the competitive grants program from $15.0 to $30.0 million.

(Corrected Version - second paragraph, p. 6)

The most interesting new development in the funding of agricultural research has been the establishment by Congress of a federally funded competitive research grant program open to all scientists and administered by the Competitive Research Grants Office of the USDA Science and Education Administration.[2] The FY 1978 appropriation act made a total of $15 million available for competitive research grants. The executive budget for FY 1979 proposed that the competitive grants program be increased by an additional $15 million. This was offset by a reduction of approximately $11 million in Hatch Act formula funding plus reductions of approximately $1.0 million in McIntire Stennis Cooperative Forestry Research, $2.0 million in special research grants and $1.5 million in rural development research.[3] The 1979 appropriations act that was finally passed by the Congress restored the cuts in the Hatch Act funds that had been recommended by the administration and continued the competitive research Grant program at the $15.0 million level. The executive budget for FY 1980 continues Hatch funding at the FY 1979 level and proposes an increase in the competitive grants program from $15.0 to $30.0 million.

Table 2. Amount and Relative Importance of Federal, State and Other Funding Sources for State Agricultural Experiment Stations, 1967 and 1977

	1967		1977	
	Amount	Percent	Amount	Percent
	($000,000)	%	($000,000)	%
Federal Sources				
Science and Education Administration (USDA)[a]	56.6	18.7	118.8	19.1
Cooperative Grants and Agreements (USDA)	10.5	3.4	12.6	2.0
Other Federal Agencies	22.2	7.3	55.6	8.9
	89.3	29.4	187.0	30.0
State Sources				
Appropriations	169.9	56.0	341.2	54.9
Sales	22.7	7.5	39.1	6.3
	192.6	63.5	380.3	61.2
Other Sources	21.4	7.0	54.6	8.8
Total	303.3	100.0	621.9	100.0

[a]Funds received by states differ from funds appropriated by the amount of direct and indirect federal administrative charges.

Source: USDA CRIS printout. (FY 1977 data are preliminary. FY 1978 and FY 1979 are not yet available.) We are indebted to Roland Robinson of the USDA Science and Education Administration for assistance in obtaining the CRIS data.

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Preliminary

Strong support for a program of competitive project research grants to be administered by the USDA had been made in two reports sponsored by the National Research Council (1973, 1977). The National Research Council recommendations reflected, in part, a judgment that the productivity of agriculture and agriculturally related research could be enhanced by making USDA research support available to scientists in departments and institutions that had not been eligible for support under the formula funding arrangements.

Administrative officers and scientists at the state agricultural experiment stations had also been generally supportive of the move to expand funds for competitive grants (Babb). Both the National Research Council and the leadership of the state experiment stations had, however, expected that an expansion of funds for competitive research grants would take place in an environment of expanded support for agricultural research. They apparently did not anticipate the trade-off between competitive grant and formula funding that emerged in the FY 1978 executive budget proposal.[4]

The argument for expanding support for agricultural research has typically drawn on two sources of support. Agricultural scientists and science administrators have pointed to the technical constraints that must be overcome to meet future food and fiber requirements. They have also argued that technical change leading to lower production costs represents one way of balancing the conflicting claims of farmers for higher incomes and of consumers for restraint in food price increases. Economists have buttressed these arguments with an expanding body of empirical research which has documented the high rates of return to past agricultural research (Boyce and Evenson; Arndt and Ruttan; Ruttan). They have also, in recent years, worked closely with research administrators to provide <u>ex ante</u> rate of return projections.[5] Both the constraint and the rate of return approaches suggest substantial underinvestment in agricultural research both in the United States and in most other countries where such studies have been conducted.

The next section of this paper presents an analysis of the behavior of individual scientists in an environment characterized by the availability of centralized project grant systems and decentralized institutional grant systems. We then examine the behavior of research administrators under the two research support systems. Finally, we attempt to draw some inferences from the behavior of research scientists and administrators under the two systems for research system efficiency. No attempt is made in this paper to present empirical estimates of the efficiency losses associated with a shift in resources from institutional to project grant support. The analysis presented here does, however, provide the framework for empirical evaluation of the efficiency gains and losses from the two systems of research support.

The Research Scientist

What objectives does the individual research scientist attempt to maximize? And how do the project (PR) and institutional (IR) research grant systems impinge on the behavior of the individual scientist?

The research scientist has been depicted as both hero (Stakman, Bradfield and Mangelsdorf) and villain (Berry). Our perspective is more modest. The typical research scientist is, as a result of inclination and conditioning, prepared to accept a rather high degree of deferred gratification within the professional reward system. In the immediate post-doctoral years the scientist is usually willing to defer immediate financial reward for an appointment which assures continued professional development--preferably documented by the accumulation of evidence of research productivity in the form of published papers. If professional productivity is accompanied by reasonable advancement in rank and earnings, the initial research orientation is reinforced. If productivity lags or is not accompanied by advancement in salary or rank, there is often a shift in emphasis toward research that is valued by clienteles other than professional colleagues. This shift toward more applied research may also be associated with a transfer to another institution whose program is more oriented to applied research. During this process the mid-career scientist may also develop certain entrepreneurial skills. These skills may run in the direction of capacity to generate research support from funding agencies and/or to mobilize the interest and the energies of colleagues to focus their efforts around problems of scientific or technical diversification which require a team effort. Development of entrepreneurial skills often comes at the expense of disciplinary capacity and direct involvement in research.

This description is, of course, highly simplified. And our ability to model is inadequate to deal with even this simplified view. However, we are able to identify several key elements of the individual scientist's objective function that appear directly relevant to the scientist's behavior under the institutional and project grant systems. The simplified behavioral model that we have developed has the following characteristics:[5]

(a) Each researcher maximizes some utility function by allocating time between leisure and work. The time devoted to work is allocated between teaching, entrepreneurial activities such as seeking research support and actively working on research.

(b) Research output is determined by the level of research support available to the researcher and the time spent actively working on research. The researcher faces diminishing returns both in the production of research funds and in the production of research.

(c) The transaction costs incurred by the individual researcher in obtaining project research support are greater than those incurred in obtaining institutional research support. However, the level of available IR support may be a binding constraint. That is, IR funds may be rationed and become unavailable before the researcher achieves the equilibrium allocation of time which maximizes utility.

(d) Income is a positive function of research output and some measure of teaching and/or extension (or public service) output depending on the way in which a particular scientist's appointment is defined.

The researcher derives satisfaction from income (generalized consumption), leisure, and perhaps also from his (her) research, teaching, and extension output directly. While his (her) utility function is probably a positive function of all of these variables, we deal with a simpler (and not markedly less realistic) case in which utility is a positive function only of consumption and of leisure.[7] Each researcher determines his (her) personal trade-off between leisure and income (generalized consumption) and the optimum allocation of labor to research, teaching, extension, and funds acquisition aspects of the job. The optimum levels of each depend on the financial rewards from doing each, the researcher's marginal productivities in each endeavor, the marginal productivity of capital (operating capital and equipment) in research, the maximum amount of institutional research (IR) funds available to the researcher, and the relative preference of the researcher for leisure over consumption (income).[8]

A useful way in which to view the process is through the researcher's individual demand for research funds (K). The demand for K can be described by a step function. The step is the result of the fact that IR funds (K_h) are limited at each institution and are rationed among its researchers, and the difference in marginal costs incurred by the researcher of obtaining IR funds and competitive project (PR) funds. Figure 1 illustrates the researcher's demand function for research funds. Total dollars of research funds demanded by the researcher are plotted on the horizontal axis. Up to the limit (K_h^{max}) of IR funds, (K_h), IR funds are cheaper to acquire than PR funds (K_g). Consequently, K_h is plotted from the origin to K_h^{max} and K_g is plotted from K_h^{max} to the right, indicating that the researcher will demand IR funds first and will demand PR funds only after IR funds are exhausted. The marginal cost of research funds to the researcher is plotted on the vertical axis. It can be measured as the money value of the foregone

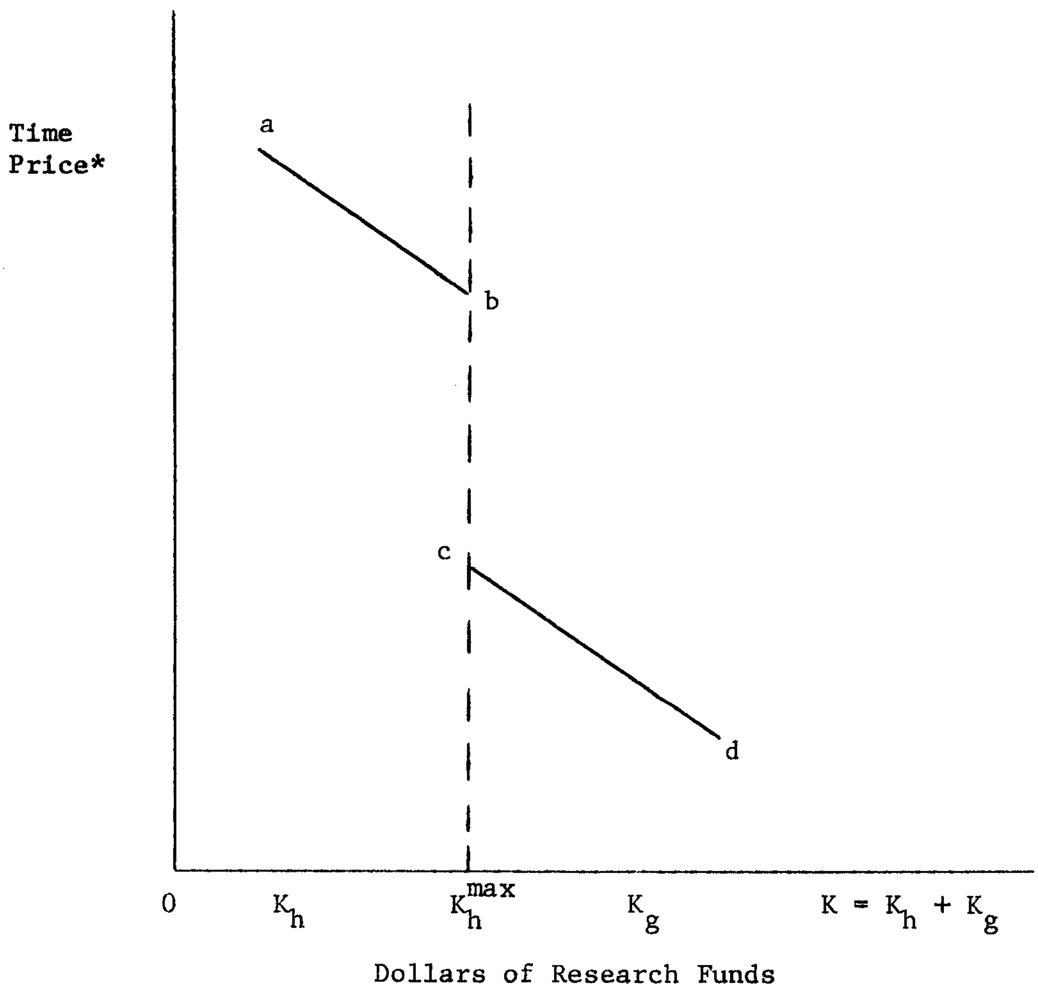

Figure 1. The Individual's Demand for Research Funds

*Marginal money value of foregone leisure required to acquire research funds.

leisure required to acquire an added dollar of research funds; it is the marginal cost of grantsmanship. The marginal cost of grantsmanship increases as the marginal real wage rate earned by the researcher increases,[9] and as the marginal products of labor spent acquiring IR funds (h_t) and PR funds (g_t) fall.

The demand for research funds by the individual researcher is traced by supposing that the marginal products of labor in both grantsman activities are initially quite low. And, both h_t and g_t are exogenously increased through, for example, a reduction in the paperwork involved in grant application. They are supposed to increase proportionally so as to maintain the difference between them; $h_t > g_t$, of course, on the presumption that it is much easier to gain access to IR funds (up to the maximum, K_h^{max}) than it is to compete successfully for competitive funds.

The ab section of the demand for research funds, then, plots the researcher's increasing demand for K_h as the marginal cost of IR funds falls. At point b the increasing demand is halted by the limit on IR funds, K_h^{max}, imposed on the researcher by the availability and allocation conventions of the local experiment station. In the ab section of the curve, PR funds are too expensive to be demanded (see equation (18) in the appendix). With a continued increase in both h_t and g_t, the marginal costs of research funds continue to fall but the researcher demands no more research funds because the marginal costs of PR funds (the value of the foregone leisure required to exercise grantsmanship) are higher than the increased income the first dollar of PR funds would bring to the researcher (see equation (19) in the appendix). The researcher is, therefore, caught in the bc portion of the curve.

With continued exogenous increases in the marginal product of labor in grantsmanship activities (g_t), the marginal cost of acquiring the first dollar of PR funds falls finally below the marginal benefit to the researcher (the increased income it would bring), thus initiating the researcher's demand for PR funds at point c. Further increases in g_t will increase the demand for PR funds (K_g) by the researcher as points farther down section cd of the curve illustrate (see equation (20) in the appendix).

Several implications can be drawn from the analysis. First, at any institution there will be those scientists with so low a demand for research funds that they are not constrained by the limit on IR funds. These will be individuals who are very productive in non-research activities relative to research and those with very high marginal products of labor in research relative to the marginal product of research funds. The former will specialize in teaching, extension, and administrative activities while the latter will be the "pencil and paper" theorists. Both will operate within the ab portion of the demand for research funds and will not be affected by K_h^{max}. Of course, the more affluent the institution, the larger will K_h^{max} likely be for any individual. We would, expect, therefore, inter-institutional differences in the proportion of faculty operating in the unconstrained, ab portion of the curve. Depending on the allocating conventions of experiment stations, some fields may be allocated relatively more than others and so the scientists within these fields will likewise be less constrained.

Second, there will likely be a number of individuals at any institution who operate in the bc portion of the demand for research funds curve. Such individuals would demand more IR funds were such funds not rationed. But, they demand no competitive funds (K_g) because the marginal cost of K_g (the marginal value of the foregone leisure) is greater than the increment to income the added funds would bring. The number of such researchers who are thus "immobilized" depends, of course, on the length of the discontinuity, bc. It will be longer (and thence the frequency of immobilized researchers greater), (i) the greater the difference in the marginal costs of IR and PR funds, (ii) the better substitutes research funds and researcher labor are in research, and (iii) the better substitutes teaching, extension, administration and research activities are in yielding income to the individual.

Third, within the range of the discontinuity, bc, while the demand for research funds is invariant, the amount of research done is not. Being barred from PR funds by their high marginal cost, the researcher may substitute his own labor for research funds and continue to increase research output, subject, of course, to greater diminishing returns than would otherwise exist. The labor intensity of the research, then, will increase as a result of the limitation on IR funds and the high cost of competitive funds.[10] This labor intensity with respect to the primary researcher's labor may also involve changes in the research output mix: more theoretical work, more use of secondary data, smaller and fewer experiments, smaller and fewer instances of primary data generation as the research becomes more labor-intensive.

Fourth, another impact of the **discontinuous demand for research funds is** to increase the labor devoted by the scientist to other aspects of his (her) appointment: teaching, extension, administration. Consulting activities can also be expected to increase. Again, this bias toward non-research activities will occur to the extent that the individual has a positive demand for income (is not in the backward bending part of his supply curve of labor) and the marginal wage rates for the non-research aspects of his (her) appointment are positive. Not only, therefore, does the limit on IR funds and the high cost of competitive funds increase the labor intensity of the research enterprise of those caught in the discontinuity, it also has the effect of increasing the labor intensity of _all_ other aspects of the individual's job.

Fifth, those not caught on the discontinuity and who have high enough demand for income (consumption), compete for PR funds and operate on the cd portion of the demand for research funds curve (see equation (20) in the appendix). The research outputs and incomes of such individuals are higher than those who operate on the ab and bc portions of the demand curve for rsearch funds. Since the marginal cost of PR funds is much higher than the cost of IR funds, the research funded with IR and PR funds will be more labor-intensive than the research of those operating on the unconstrained, ab portion of the curve. Whether the research done on the cd portion of the curve is more or less labor-intensive than those caught in the discontinuity depends on the difference in the marginal costs of PR and IR funds: the greater the difference the more likely the research of those caught in the discontinuity will be more labor-intensive than those demanding PR funds. One way of looking at this is that as the difference between the costs of the two types of funds increases, more of the scientist's time must be devoted to grantsmanship and less to direct research activities if he (she) is to compete for PR funds.

Sixth, it is very likely that a reduction in IR funds with the consequent increased stringency with which remaining IR funds would be rationed among researchers (a shift to the left of K_h^{max} in figure 1) will increase the difference between the marginal costs of IR and PR funds. As IR funds are increasingly rationed, more individuals will be pushed from the bc to the cd portion of the demand for funds curve and will compete for PR funds. The increased number of competitors for PR funds will drive down the probability of acceptance of any given proposal and so raise the marginal cost of grantsmanship. A transfer of the reduced IR funds to PR purposes (as the USDA proposed in 1978) will increase either the number of PR projects funded or the level of funding per project and so increase the expected yield per proposal. The net effect of these two changes is unclear. If academics are as risk averse as recent writings on the economics of academic tenure and retirement suggest, the decline in the probability may well be more important than the increase in PR funds. If so, the marginal cost of PR funds will rise. A possible result of transferring funds from IR to PR purposes, therefore, will be to increase the proportion of researchers immobilized in the bc portion of the curve.

Seventh, it is worth noting that given a distribution of grantsmanship skills among scientists, the greater the difference between the marginal costs of IR and PR funds, the greater the likelihood that specialization of function will arise among scientists. The more skilled as grantsmen will specialize in the activity doing little or no actual research.[11] And with the PR funds they will hire scientists relatively more skilled in research to which they will allocate research funds. Of course, what is being described is a process somewhat similar to which our present experiment station administrators and researchers differentiated themselves. One effect of the current attempts by the USDA to shift funds from IR to PR purposes will be to reshuffle the scientific manpower deck so as to disemploy current experiment station administrators and employ new grantsmen-administrators presumably more willing to allocate funds to problems which have been ranked high on the national priority agenda--as interpreted by the USDA or by members of the appropriate House and Senate committees and their aides.

The Research Administrator

An assessment of the efficiency implications of a project research grant system relative to an institutional research grant system must consider the effects of the two systems on the behavior of the research administrator as well as the behavior of the individual scientist. In this section we suggest how the project and institutional research grant systems impinge on the behavior of the research administrators. We shall be particularly concerned with the impact on the behavior of the director of an agricultural experiment station, research center or laboratory located within a university environment.

Our description of the objective function of the research administrator is largely intuitive. Kaldor has repeatedly pointed to the dearth of systematic knowledge about the decision making processes used by research administrators (1971, 1978). Most of the knowledge that we do have is based on casual observation and introspection. Nevertheless it does seem feasible to specify some of the elements that enter into the decisions of research administrators and scientists.

The typical research manager tends to have a view of the world which places a heavy weight on the value of new knowledge and new technology and places a low weight on both the direct and indirect costs of research and of technological change. The administrator visualizes an almost "endless frontier" waiting to be discovered and with limited financial, physical and professional resources. The administrator's standing, both within his (her) own institution and among outside collegiate and clientele constituencies, is directly related to the ability to assemble or develop a research staff that is recognized for the quality of its work or its value to clientele constituencies. Within public sector institutions, where the salary structure is bureaucratically determined and has little flexibility at the top, prestige considerations carry greater weight than in the private sector where the output of the research laboratory is evaluated more directly in terms of the enhancement of the firm's profits.

The net effect of these considerations leads a research director to measure success in terms of the capacity to acquire additional resources and the ability to utilize these resources productively. The measurement of the quality or the value of research output at the individual scientist or research team level is highly subjective and the management of research enterprises is highly collegial. These factors tend to lead to an emphasis on the quality of the major input, professional personnel, relative to the value of research output. Emphasis on more effective monitoring of research output is greatest in those cases where there is strong clientele pressure. Clientele pressure on research management is reasonably strong in state and federal agricultural research programs because of the close feedback loop between farmers, legislators and research institutions (Guttman).

The above description of the elements that enter into the objective function of the research administrator or manager is not inconsistent with the utility function of the bureau manager that has been suggested in the literature on bureaucratic behavior (Niskanen; Ruttan). In that literature it is assumed that the bureau manager's utility is a function of: (a) the bureau's output, (b) the bureau's discretionary budget. In the case of the agricultural experiment station or the agricultural research institute, we can interpret bureau size in terms of research staff and the output of applied research that is valued by the research institution's clientele. Discretionary budget can be interpreted in terms of funds to support more fundamental (basic or supporting) research and for related professional activities (seminars, symposiums) that serve to enhance the capacity of the research staff or the prestige of the research unit.

If incremental growth in research funding is primarily in the form of project rather than institutional research support, as suggested in the introductory section, one effect will be to reduce the discretionary resources available to state experiment station directors. A higher proportion of institutional support funds will have to be devoted to salary and overhead items. Capacity to mobilize resources for problems of significance at the state or regional level will be reduced.

This description of the utility function of the research manager involves an even greater simplification of a complex reality than our description of the utility function of the individual research scientist.

It does appear, however, to catch important elements of the typical research manager's motivation. We are now ready to combine our analysis of the effects of the institution research grant (IR) and the project research grant (PR) systems on the behavior of the individual scientist and research administrator, on the efficiency or the productivity of the research system, and on the strategy alternatives available to research administrators.

Some Research Management and Policy Implications

It seems quite clear that a system which combines substantial internal institutional (IR) and external project (PR) grant funding is consistent with the objective functions of both individual research scientists and science administrators.

From the perspective of the individual scientist the internal institutional support provides assurance of tenure. The external project support assures sufficient independence to permit the achievement of the professional as well as purely economic goals that enter into the researcher's objective function. Many young researchers see the possibility of external PR funding as an opportunity to achieve freedom from in-house pressures to conform to institutional research strategies and objectives.

From the perspective of the experiment station or research institute director the internal institutional support provides assurance of reasonable program and staffing continuity. The external PR funds appear to represent an opportunity to escape from the funding constraints of traditional clientele and an opportunity to devote larger staff resources to innovative or fundamental research objectives that are less subject to review and evaluation by traditional clientele.

Research efficiency

It would be surprising, however, if optimization of the objective functions of research scientists and administrators would under most circumstances lead to system efficiency. System efficiency is a function of the institutional environment, including the structure of incentives and opportunities, in which scientists and administrators carry out their professional responsibilities. When we examine the implications for the behavior of scientists and research administrations under the IR and PR systems, some rather clear-cut empirical generalizations concerning system efficiency emerge.

First, the external PR grant system diverts efforts by individual scientists from research to grant-seeking and related entrepreneurial activities. This is why the PR portion (section cd) of the individual researcher's demand for funds lies below the IR portion (section ab).[12] Most university scientists can quote examples of the colleague who has spent much more time preparing grant requests for the support of summer research than was spent actually carrying out the grant-supported research. More directly to the point, in 1978 the USDA, which administered a competitive grant program of $15 million, received over 1,100 research proposals involving funding requests for over $200 million (Science and Education Administration, May 1978). Similar ratios have been noted for other grant programs (Leopold). In addition to the time devoted to the preparation of unfunded grant proposals there is also very substantial time devoted to peer review and administration.

Excessive allocation of scientific effort to grant-seeking activity is clearly induced by a major structural feature of the competitve grant system. To the individual researcher the supply of PR funds appears relatively elastic (with respect to effort devoted to grant seeking). Each individual project is small relative to the resources available to the granting agency. In the aggregate, however, the supply of research funds is relatively inelastic in the short run. An increase in the number of project submissions results in an increase in the share of research resources devoted to grant seeking relative to research and an increase in the bureaucratic resources devoted to grant management. It may also result in smaller average size of individual grants and fragmentation of research effort.

Second, in a system in which institutional support is limited primarily to personnel support for core scientific staff (such as tenured professors) and capital equipment (such as laboratory space and computing equipment), incremental research costs must be covered by project grants. Over time, a research institute committed to solving a particular scientific and technical problem, adapting soybeans to shorter growing season environments for example, may find its staff responding more to priorities of external funding institutions rather than concentrating its effort on the crop improvement mission. It is not difficult to imagine a situation where a university administration begins to value its agricultural (or space science) research capacity less for the significance of the scientific and technological knowledge it produces than for the overhead generated by research grants or contracts.

This problem appears to be most acute in situations in which institutional research support has been closely linked to, or hidden by, reduced teaching loads. In the 1950s and 1960s many universities used expansion of undergraduate education to support the expansion, almost surreptitiously, of their institutional research support (Keyfitz). This has created two important problems in a period of declining or shifting undergraduate enrollment. Institutional research support by discipline or problem area expanded in response to differential rates of growth in undergraduate enrollment. Likewise during a period of declining or shifting enrollment, institutional support is eroded for considerations unrelated to scientific opportunity or technological priority. As noted earlier, institutional support for agricultural research has not been as closely coupled to undergraduate enrollment as in many other areas. There are, however, substantial pressures in some states from university administrators and state legislative committees to conform to university-wide standards with respect to student-teacher ratios. In the future, effective allocation of institutional research resources will require the development of budgeting mechanisms that more effectively uncouple the institutional support for teaching and research activities.

Research strategies

What are the policy options available at the level of the individual agricultural experiment station or research institute when confronted with a world in which institutional support is severely limited, and incremental project research (PR) grant funds are increasingly available from the U.S. Department of Agriculture, the National Science

Foundation, and other governmental and foundation sources? Three alternative strategies are available:

One alternative is a "research entrepreneurship" strategy. This strategy, as followed by some experiment station directors, is to utilize most of the institutional support funds from federal formula funds and state matching funds, primarily to cover scientific staff and staff-related costs. Staff are then encouraged to "prospect" for research program support among public and private agencies which make research grants or which contract research. This is the standard pattern for research-oriented academic departments or schools which do not have access to sources of substantial institutional support.

This research entrepreneur model has some important advantages for the individual experiment station or research institute. It permits recruitment of a larger research staff than a strategy in which institutional support is reserved for research program support. It probably results in a selection process in which staff with research entrepreneurial ability are attracted to research stations which emphasize a research entrepreneurship strategy. It provides research administrators with an independent judgment of the quality of staff research effort. Quality is inferred not only from publication in peer-reviewed journals but also from the amount and source of project research funds attracted.

There are also costs to both the individual station and the research system. We have observed that the development of research entrepreneurship capacity, particularly if developed relatively early in a scientist's career, may be competitive with the development of capacity to advance scientific knowledge. There are also serious institutional repercussions for a research entrepreneurship strategy when the supply of grant or contract funds in areas that are important to the institution's central thrust declines. This may be a particularly serious problem for a state agricultural experiment station where research effort is expected to pay off in terms of state economic and social development objectives.

A second alternative is an "in-house" strategy. In an "in-house" strategy, research is limited to those research programs and activities which can be supported by federal formula funds, state matching funds and special appropriations, endowments and other forms of relatively unrestricted long-term institutional support. An advantage of the "in-house" approach is that it enables the research director to assemble a staff of scientists who are primarily motivated toward the development and exercise of scientific capacity rather than entrepreneurial capacity. It permits a focus on relatively long-term and fundamental research problems. And it provides a greater opportunity for the scope and direction of the research program to be set by the experiment station or research institute rather than by granting agencies.

There are also costs to an "in-house" strategy. In the presence of a strong director the research decision process may become too authoritarian. The security of research funding may result in a research program that is too routine--to filling in the gaps in the literature or to meeting the short-run information needs of clientele groups. In the presence of a weak director the research resource allocation system may become too political--too responsive to the pressures of strong department chairmen or research scientists who generate strong local clientele support. An "in-house" strategy may also impose excessive limits on the size of the research unit.

A third alternative which may be the most "efficient" strategy in an "nth best" world would appear to include elements of both the research entrepreneurship and the "in-house" strategy. These elements would include:

(a) Recognition that the aggregate supply of research resources is likely to be more responsive to the efforts of research directors, or of directors acting as a group, than to the efforts of individual researchers. This may imply that the entrepreneurial (political) activities of experiment station directors and deans of agriculture may be more productive in their efforts to expand the availability of research resources than in their role as allocators of "in-house" research resources.

(b) Retention of sufficient control over "in-house" research resources to provide sufficient seed money for young researchers to enable the research administration and outside funding agencies to make accurate judgments of their research and entrepreneurial capacities and to back the high-risk or speculative research of serious researchers of proven capacity that may later serve to attract external support.

(c) Allocate the balance of "in-house" funds to salary and related costs of scientific staff on the expectation that most mid-career and senior staff have reasonable capacity to attract external funds.

Research policy

A research policy that forces research managers into adopting "nth best" strategies is by definition less than optimal when viewed from a broad national or social perspective.

We have noted that the effect of a system which appears optimal to the individual scientist or to the individual research manager in a world characterized by limited institutional support and substantial project research support alternatives is to (a) induce both excessive allocation of professional resources to grant seeking and (b) contribute to the disintegration of the capacity to undertake major mission-oriented applied research programs. These two sources of inefficiency can be reduced by utilizing an institutional research strategy as the primary device for the support of mission-oriented applied research and for the basic research required as a direct input into an applied research program.

In contrast there is substantial evidence to support the claim of efficiency for the institutional support system. High rates of return have been attributed to the state and federal agricultural research systems in the United States, to a number of older research institutions in former colonial countries (such as the Rubber Research Institute of Malaysia), and to the older units of the CGIAR-sponsored international agricultural research system (Evenson; Ruttan). It would be extremely difficult to imagine that the long-term research effort required to develop the high-yielding clones which have revolutionized productivity in the Malaysian rubber industry could have been accomplished on the basis of a series of project grants from a colonial research secretariat in London.

The inferences drawn from agricultural research are consistent with the experience of a number of highly productive industrial research programs. Mansfield has documented rates of return to industrial research in the same range as the rates of return to public sector agricultural research (Mansfield, p. 157). The more productive private research programs have typically been those which have combined long-term sustained support by a firm with a sufficiently broad product line to be able to utilize a substantial share of the product of a major "in-house" research program (Mueller).

Finally, one can point to the productivity of a number of long-term institutional research support activities by the private foundations. The support by the Carnegie Institution for the fundamental studies on inheritance in maize by George H. Schull is a classic example (Sprague). The Rockefeller Foundation support for the research program of the Office of Special Studies in the Mexican Ministry of Agriculture over several decades (from the mid-1940s to the early 1960s) established the basis for the research on wheat and maize that has led to yield increases in a number of tropical countries (Hayami and Ruttan). The long-term support for the research program of Resources for the Future has been a major factor in establishing resource economics as a major field of economic research in the United States.

Some qualifications

There are several qualifications or counter arguments to the conclusions set out in the previous sections.

Long-term institutional research support can also become a source of inefficiency. Institutional research programs are subject to the danger of becoming too conventional or to losing a sense of urgency with respect to their mission. We noted earlier that project grant support has at times been defended on the basis that it forces a research system to become more responsive. We find no fault with this argument as long as project research support remains relatively small--as long as its impact is to encourage the exploration of new opportunities within the broad research mission of an institution.

There are also other devices for offsetting geriatric tendencies in a mature research institute. The development of cost sharing arrangements between public research institutes and clientele groups, or user representation on boards of directors or advisory committees, are among the possibilities. An important factor in the case of the state agricultural experiment stations has been their location within a university environment. The interaction between graduate training and research and the opportunities to draw on professional capacity in related fields have contributed to research productivity.

Another argument which must be dealt with is whether a competitive PR support system is an effective way of taking advantage of the research capacities that exist outside of institutionally funded research programs. A major argument in favor of the new USDA project grant program is that it would be able to draw on professional resources in departments that do not receive experiment station funding and in institutions that were not part of the land grant system. The project grant programs of the National Science Foundation are available to individual scientists in institutions which have very little institutional research capacity.

This argument is only partially compelling. The United States has been reasonably successful in evolving a dual system of colleges and universities in which those institutions that are capable of organizing effective graduate training and research activities are sharply differentiated from those that do not possess such capacity. The major research universities probably have greater capacity to manage efficiently a program of research grants based primarily on the quality of individual projects than a central granting agency such as the USDA or the National Science Foundation.

For the colleges and universities which do not have substantial graduate programs, faculty research must be justified primarily on the basis of contribution to the viability of the teaching programs. A limited commitment of faculty effort to scholarship and research contributes to the vitality of undergraduate teaching programs. Even in institutions which are primarily committed to an undergraduate education mission, our experience leads us to believe that institutional support for a program of small grants would be more efficient than a grant program that is centralized in a Washington agency.

APPENDIX

A model of the maximization of utility by an individual researcher is presented. The model allows the researcher choice over the time spent in research, grantsman activities, and in leisure. Teaching, while an integral part of the activities of most university-based researchers, is excluded from consideration as a needless complication.[13]

Let the utility function of the researcher be

$$(1)\quad U = u(C,L)$$

where C represents consumption and L represents leisure.

The production of research output is dependent on the level of research funds generated (K) and the time spent doing research (T_r). The research production function can be represented as:

$$(2)\quad R = r(K, T_r); \quad r_k, r_t > 0; \; r_{kk}, r_{tt} \leq 0.$$

Note that funds gathered from institutional research sources (K_h) and from competitive grant sources (K_g) are simply summed into an aggregate funds variable,

$$(3)\quad K = K_h + K_g,$$

implying that to the researcher the two sources of funds are perfect substitutes.

The production of research funds is differentiated by the source of the funds. The respective production functions for institutional and competitive grant funds are:

(4) $K_h = h(T_h); \qquad h_t > 0,\ h_{tt} \leq 0.$

(5) $K_g = g(T_g); \qquad g_t > 0,\ g_{tt} \leq 0.$

Further, the model specifies a limit to the availability of institutional funds, K_h^{max}, implying a maximum amount of time that can be spent in obtaining institutional funds, T_h^{max}. Moreover, the marginal productivity of time spent seeking institutional funds is presumed to be greater for all levels of institutional funds than that spent seeking competitive funds. This reflects the realities of competitive grantsmanship. Typically, competitive proposals must be more detailed than institutional proposals and many more proposals must be written per dollar of competitive funds obtained than per dollar of institutional funds. This assumption is written

(6) $$g_t \Big|_{T_g = 0} < h_t \Big|_{T_h = T_h^{max}} .$$

This assumption implies that institutional support will be exhausted before competitive funds are sought.

Finally, income is assumed to be a function of research output:

(7) $I = i\{R\}; \quad i_t > 0,\ i_{rr} \leq 0.$

And, total available time (T) is exhausted:

(8) $L + T_h + T_g + T_r - T = 0$

where $T_h + T_g + T_r$ represents total work time.

The individual's choice problem can be represented by the maximization of the following Lagrangian:

$$(9)\quad U^* = u(C,L) - \lambda_1[C - i\{r(h(T_h) + g(T_g),\ T_r)\}] - \lambda_2[L + T_h + T_g + T_r - T] - \lambda_3[T_h - T_h^{max}]$$

The first order conditions of this function are:

$$(10)\quad \partial U^*/\partial C = u_c - \lambda_1 = 0$$

$$(11)\quad \partial U^*/\partial L = u_1 - \lambda_2 = 0$$

$$(12)\quad \partial U^*/\partial T_h = \lambda_1 i_r r_k h_t - \lambda_2 - \lambda_3 = 0$$

$$(13)\quad \partial U^*/\partial T_g = \lambda_1 i_r r_k g_t - \lambda_2 = 0$$

$$(14)\quad \partial U^*/\partial T_r = \lambda_1 i_r r_t - \lambda_2 = 0$$

$$(15)\quad \partial U^*/\partial \lambda_1 = -C + i\{R\} = 0$$

$$(16)\quad \partial U^*/\partial \lambda_2 = -L - T_h - T_g - T_r + T = 0$$

$$(17)\quad \partial U^*/\partial \lambda_3 = -T_h + T_h^{max} = 0$$

Three possible cases emerge from the first order conditions. The first illustrates a researcher choosing a level of leisure at which institutional funds are not exhausted and competitive funds are not sought. Thus, $\lambda_3 = 0$ and

$$(18)\quad i_r r_k h_t = i_r r_t = u_1/u_c\ .$$

The marginal rate of substitution of leisure for goods equals the increments to income brought about by increments of time spent seeking institutional funds and in direct research activity. It should also be noted that this is the condition that would be met in equilibrium if institutional funds were unlimited within the range demanded by the individual researcher.

The second case describes a researcher caught on the discontinuity embodied in equation (6). Institutional funds are exhausted but no competitive funds are obtained because their price in terms of the value of foregone leisure time is too high. The condition for this situation to occur is:

$$(19)\quad i_r r_k h_t - \lambda_3/u_c = i_r r_t = u_1/u_c$$

where λ_3 indicates the cost of the individual researcher in terms of lost marginal utility of the constraint on institutional funds. Were the marginal product of time spent obtaining funds a continuous function of time, the individual's research output and resulting income would be greater. Furthermore, since added institutional research funds are unavailable and competitive funds too expensive, some additional time will be spent in direct research in order to equate $i_r r_t$ with $i_r r_k h_t - \lambda_3/u_c$ rather than simply $i_r r_k h_t$ (λ_3/u_c being positive). Since more time will be spent in direct research activity relative to funds acquisition activities and thence relative to research capital (K) in the constrained than in the unconstrained case, research will be more labor-intensive.

The third case depicts a researcher whose utility function justifies the large amount of extra foregone leisure required in order to obtain competitive funds. The condition which must be met is:

$$(20)\quad i_r r_k h_t - \lambda_3/u_c = i_r r_k g_t = i_r r_t = u_1/u_c.$$

This researcher seeks competitive funds, has a higher level of research output and income than either of the other two individuals. Research output and income are both lower, however, for this individual than if institutional funds were unconstrained or competitive funds not so costly. The added time spent in grantsman activities (over and above that necessitated to garner institutional funds had they been unlimited) might be considered a dead-weight loss resulting from the differential costs of institutional and competitive funds. Relative to the unconstrained case, the research this individual does is more labor-intensive.

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FOOTNOTES

[1]Funds allocated to the states under the Hatch Act are, except for funds reserved for cooperative regional research efforts, allocated to the state agricultural experiment stations by a formula based on the number of farms and the size of the rural population in each state. The several sources of federal funds for state agricultural research are identified in the latest annual report of the Cooperative State Research Service (1976). Factors affecting the support for state agricultural experiment stations have been analyzed by Huffman and Miranowski (1978), Peterson (1969), Heady (1961, 1962) and Dalrymple (1962).

[2]A program of special grants that were competitive among state agricultural experiment stations was initiated in 1970. These funds rose from $2.8 million in 1970 to $16.2 million in 1979 (table 1).

[3]The details of the 1978 executive budget proposals in support of the Cooperative State Research Service are from the Science and Education Administration _Experiment Station Letter_ 1438 (January 27, 1978). The new grant program was discussed in an editorial by Gary A. Strobel in the March 3, 1978, issue of _Science_. For a more detailed description of the competitive grants program see the Science and Education Administration (1978) announcement in the _Federal Register_ of March 7, 1978.

[4]Dr. M. Rupert Cutler (Assistant Secretary for Conservation,

Research, and Education, USDA) appeared to be surprised by the results of his own budgeting efforts. In response to committee questioning on this point he responded, "That apparent relationship was unintended. By that I mean the relationship between beginning a competitive grant research program open to all agricultural scientists and the level of the Hatch Act budget request." Dr. Cutler went on to explain that many of the programs of the USDA (entitlement and regulatory programs) are legislatively determined. Given a budget ceiling, the remaining funds available for agricultural research programs are fixed. Thus the only available method to initiate the competitive grants system was the reduction of other research areas.

[5]For a review of the methodologies for estimating ex ante values of return see Shumway (1977). For an attempt to develop ex ante rate of return estimates see Araji, Sim and Gardner (1978).

[6]Since developing the model outlined below, our attention has been drawn to similar models developed by William E. Becker, Jr. (1975, 1979). Becker's models are, however, designed to address different questions.

[7]That the individual derives satisfaction from working does not affect the results unless the individual derives satisfaction in different degrees from the various aspects of his (her) job description and in particular unless differential satisfaction is drawn from IR and PR financed research.

[8]A mathematical exposition of a model of the individual researcher is presented in the appendix. The notation used in the text conforms to that in the appendix.

[9]It is presumed that leisure is a normal good and that the

researcher does not operate on the backward bending part of his supply of labor.

[10]In this instance and hereafter when labor intensity is discussed, it is researcher or project director labor that is being referred to. Within the limits of IR and PR funds, other labor (graduate students, post-doctoral fellows, research assistants, secretaries and the like) may be employed to carry out particular facets of the research.

[11]There is some evidence to the effect that younger scientists are more active in journal publication than older scientists and that the marginal value of a journal article, in terms of income, declines with the scientist's age (Peterson, 1973, p. 14).

[12]See also both references to Foster (1979).

[13]The introduction of teaching into the model allows another conclusion to be drawn: that the constraint on institutional research funds will bias the work effort of all but the "leisure-loving" researcher (see equation (18) below) away from research and into teaching in comparison with a situation in which institutional funds were not constrained. In a time when the demand for teaching resources is reduced, this seems counterproductive. The other conclusions of the model presented below remain unaltered.

REFERENCES

Araji, A. A.; Sim, R. V.; and Gardner, Richard. Returns to Public Investment in Agricultural Research and Extension in the Western Region. Department of Economics, University of Idaho, Moscow, January 1978.

Arndt, Thomas M., and Ruttan, Vernon W. "Valuing the Productivity of Agricultural Research." In Resource Allocation and Productivity in National and International Agricultural Research. Edited by Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977, pp. 3-25.

Babb, Emerson M. Marketing Research at State Agricultural Experiment Stations: Problems and Possible Solutions. Purdue University Agricultural Experiment Station Bulletin 150, January 1977, pp. 12, 25.

Becker, William E., Jr. "Professional Behavior Given a Stochastic Reward Structure." Department of Economics, University of Minnesota, 1979. (Mimeographed.)

Becker, William E., Jr. "The University Professor as a Utility Maximizer and Producer of Learning, Research and Income." Journal of Human Resources 10 (Winter 1975):109-115.

Berry, Wendell. Culture and Agriculture: The Unsettling of America. New York: Avon, 1978.

Blattenberger, G. R., and Taylor, L. D. "Aggregation of Demand Functions when Budget Sets Are Non-Convex." In Report to the Electric Power Research Institute. Edited by L. D. Taylor, G. R. Blattenberger and P. K. Verlegar, Jr. Palo Alto: EPRI, November 1976, Appendix 2.

Bowers, R. "The Peer Review System on Trial." American Scientist 63 (6) (November-December 1975):624-626.

Boyce, James K., and Evenson, Robert E. National and International Agricultural Research and Extension Programs. New York: The Agricultural Development Council, 1975.

Bredahl, Maury E., and Peterson, Willis L. "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations." American Journal of Agricultural Economics 58 (November 1976):684-692.

Cole, Stephen; Rubin, Leonard C.; and Cole, Jonathan R. "Peer Review and the Support of Science." Scientific American 237 (October 1977): 34-41.

Cutler, M. Rupert. "Statement." In Appraisal of Title 14 (Research), Agricultural Act of 1977. Hearings before the Subcommittee on Department Investigations, Oversight and Research of the Committee on Agriculture, Serial No. 95-RR, House of Representatives, 95th Congress, 2d sess., February 23, 1978. Washington, D. C.: Government Printing Office, 1978, pp. 91, 92.

Dalrymple, Dana. "Comment on 'Public Purpose in Agricultural Research and Education'." Journal of Farm Economics 44 (May 1962):444-453.

Dupree, A. Hunter. Science in the Federal Government: A History of Policies and Activities to 1940. Cambridge: Harvard University Press, 1957.

Evenson, Robert E. "Comparative Evidence on Returns to Investment in National and International Research Institutions." In Resource Allocation and Productivity in National and International Agricultural Research. Edited by Thomas M. Arndt, Dana G. Dalrymple, and

Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977, pp. 237-264.

Fishel, Walter L., ed. Resource Allocation in Agricultural Research. Minneapolis: University of Minnesota Press, 1971.

Foster, Edward. "Competitively Awarded Federal Grants." Department of Economics, University of Minnesota, January 1979. (Mimeographed.)

Foster, Edward. "The Treatment of Rents in Cost-Benefit Analysis." Center for Economic Research, Department of Economics, University of Minnesota, Discussion Paper No. 79-106, January 1979.

Gustafson, T. "The Controversy over Peer Review." Science 190 (December 12, 1975):1060-1066.

Guttman, Joel M. "Interest Groups and the Demand for Agricultural Research." Journal of Political Economy 86 (June 1978):467-484.

Hadwiger, Don. "Changes in Political Support for Agriculture." In Food and Agriculture Policy Issues. Edited by Luther Pickrel University of Minnesota Agricultural Extension Service, Special Report 71, 1978, pp. 43-49.

Hayami, Yujiro, and Ruttan, Vernon W. Agricultural Development: An International Perspective. Baltimore: The Johns Hopkins University Press, 1971.

Heady, Earl O. "An Alternative View of State Expensitures." Journal of Farm Economics 44 (May 1962):454-461.

Heady, Earl O. "Public Purpose in Agricultural Research and Education." Journal of Farm Economics 43 (August 1961):566-581.

Huffman, Wallace E., and Miranowski, John A. "An Analysis of State Expenditures on Experiment Station Research." Department of Economics, Iowa State University, March 1978. (Mimeographed.)

Kaldor, Donald R. "Social Returns to Research and the Objectives of Public Research." In Resource Allocation in Agricultural Research. Edited by Walter L. Fishel. Minneapolis: University of Minnesota Press, 1971, pp. 62-79.

Kaldor, Donald R. "Some Issues in Specifying an Objective Function for Evaluating Public Agricultural Research." Department of Economics, Iowa State University, 1978. (Mimeographed.)

Keyfitz, Nathan. "The Impending Crisis in American Graduate Schools." The Public Interest 52 (Summer 1978):85-97.

Leopold, A. Carl. "The Burden of Competitive Grants." Science 203 (February 16, 1979):607.

Mansfield, Edwin; Rapoport, John; Romeo, Anthony; Villani, Edmund; Wagner, Samuel; and Husic, Frank. The Production and Application of New Industrial Technology. New York: Norton, 1977.

Mayer, Andre, and Mayer, Joan. "Agriculture, the Island Empire." Daedalus 103 (Winter 1974):83-96.

Meier, Kenneth J. "The Agricultural Research Service and Its Clientele: The Politics of Food Research." Paper presented at the 1977 Annual Meeting of the Southwestern Political Science Association, Dallas, 1977.

Mueller, Willard F. "The Origins of Basic Inventions Underlying Du Pont's Major Product and Process Innovations, 1920-1950." In The Rate and Direction of Inventive Activity. Edited by Richard R. Nelson. Princeton, N. J.: Princeton University Press, 1962, pp. 323-353.

National Research Council. Report of the Committee on Research Advisory to the USDA. Springfield, Virginia: National Technical Information Service, 1973.

National Research Council. World Food and Nutrition Study: The Potential Contributions of Research. Washington, D. C.: National Academy of Sciences, 1977.

Niskanen, William A. "Bureaucrats and Politicians." The Journal of Law and Economics 18 (December 1975):617-644.

Paarlberg, Don. "A New Agenda for Agriculture." Policy Studies Journal 6 (Summer 1978):504-506.

Pastore, Jose, and Alves, Eliseu R. M. "Reforming the Brazilian Agricultural Research System." In Resource Allocation and Productivity in National and International Agricultural Research. Edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977, pp. 394-403.

Peterson, Willis L. "The Allocation of Research, Teaching and Extension Personnel in U.S. Colleges of Agriculture." American Journal of Agricultural Economics 51 (February 1969):41-55.

Peterson, Willis L. "Publication Productivities of U.S. Economics Department Graduates." Staff Paper P73-27, Department of Agricultural and Applied Economics, University of Minnesota, October 1973.

Puterbaugh, Horace L. "An Application of PPB in the Agricultural Research Service." In Resource Allocation in Agricultural Research. Edited by Walter L. Fishel. Minneapolis: University of Minnesota Press, 1971, pp. 316-325.

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

Shumway, C. Richard. "Models and Methods Used to Allocate Resources in Agricultural Research: A Critical Review." In Resource Allocation and Productivity in National and International Agricultural Research. Edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977, pp. 436-457.

Sprague, George F., ed. Corn and Corn Improvement. New York: Academic Press, 1955.

Stakman, E. C.; Bradfield, Richard; and Mangelsdorf, Paul C. Campaigns against Hunger. Cambridge: Harvard University Press, 1967.

Stein, Bernard R. "Public Accountability and the Project Grant Mechanism." Research Policy 2 (1973):2-16.

Strobel, Gary A. "A New Grants Program in Agriculture." Science 199 (March 3, 1978):935.

Ulbricht, Tilo L. V. "Contract Agricultural Research and Its Effect on Management." In Resource Allocation and Productivity in National and International Agricultural Research. Edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977, pp. 381-393.

U.S. Department of Agriculture. Cooperative State Research Service. Funds for Research at State Agricultural Experiment Stations and Other Cooperating Institutions, 1975. CSAS 15-11. January 1976.

U.S. Department of Agriculture. Science and Education Administration. To Administrators of Cooperating State Research Units. Experiment Station Letter 1455, May 26, 1978.

U.S. Department of Agriculture. Science and Education Administration. "Competitive Grants for Basic Research: Plant Biology and Human Nutrition." Federal Register 43 (March 7, 1978):9432-9440.

U.S. Department of Agriculture. Science and Education Administration. To Directors of State Research in Agriculture and Forestry. Experiment Station Letter 1438, January 27, 1978.