Setting Efficient Incentives for Agricultural Research: Lessons from Principal-Agent Theory II

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by

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Abstract

by Wallace E. Huffman and Richard E. Just

This paper presents one of the first systematic treatments of economic incentives in the management of academic research and major inefficiencies in common funding mechanisms. Building on well-known but unusual attributes of research whereby the research payoff is only the "best" of scientists' outputs, payoffs are highly uncertain, asymmetric information exists on scientists' effort, and scientists' are more risk averse than administrators, we consider how incentives should be structured to elicit optimal research effort and payoffs using a principal-agent model with heterogenous ability across scientists. We then conduct a systematic analysis of the implications from the model for the three major forms of agricultural experiment station funding--external grant programs, incentive contracts with outsiders, and formula/program funding. External competitive grant programs are shown to be a relatively inefficient funding mechanism.

Key words: research management, research incentives, heterogenous ability, agriculture, principal-agent theory, implicit contracting, funding mechanisms.

Setting Efficient Incentives for Agricultural Research: Lessons from Principal-Agent Theory II

At least since the 1950s, studies have shown unusually high productivity of public agricultural research (e.g., Griliches; Huffman and Evenson; Ruttan; Schultz). In response, many have asked why more funds are not allocated to public agricultural research. More recently, following the large budget deficits of the 1980s, funding conditions have tightened and forced both the research agencies of the U.S. Department of Agriculture and many of the state agricultural experiment stations (SAES) into a contracting mode. Under unprecedented budget pressures, administrators and public decision makers have struggled to set priorities to reduce budgets without significant loss of productivity. In response, considerable debate has emerged over the last decade about how to organize and manage agricultural research (e.g., Alston, Norton, and Pardey; Huffman and Just 1994, 1999a; Just and Huffman).

One school argues that priorities should be set at a national level and then competitive grant programs should be used to allocate funds according to these priorities. Another school argues that national priority setting may ignore research opportunities with local specificity or non-national groups of benefactors, and that competitive grants programs have high transactions costs and foster too many projects with short-term and relatively certain payoffs. Some limited empirical work has been offered supporting the latter view (Huffman and Just 1994, 1999a). Interestingly, the analysis of these issues to date has not produced an explanatory theory.

Progress has been largely to identify issues, canvass views, and express a priori impressions and intuition.

There has, however, been a longer term debate about how best to foster, organize, and manage agricultural research. Almost two decades ago T. W. Schultz (1980, 1982, 1983, 1985) spoke out against the tendencies for national priority setting and central planning of agricultural research, over-organization of institutional research, directing research from the top, requiring elaborate documentation/justification of research efforts, and treating/managing research as a routine activity. Furthermore, he concluded: "Although money, facilities and competent agricultural scientists are necessary to do worthwhile research, it is not a routine activity. It is, indeed, a subtle, elusive human activity that is difficult to foster, promote and maintain." [Schultz 1980, p. 16]

More recently Holmstrom and Levitt have identified unusual dimensions of the more general innovation process that make setting efficient incentives for innovation relatively difficult compared to industrial production or marketing. These differences mean that incentives, management practices, and organizational structures that work well for industrial production/ marketing cannot be successfully applied to innovation because they will stifle innovations. Because academic research is undertaken to obtain discoveries and advances in knowledge, it is innovative activity. Hence, incentives and organizational structures are very important to an efficient and effective organization of agricultural research.

This paper presents a conceptual analysis of some of the important issues in the organization and management of academic research. In particular, we apply principal-agent theory to derive optimal compensation schemes for scientists when scientists differ in ability, risk aversion, cost of effort, and reservation utility, and to show the optimal trade-off between institutional risk and scientists' abilities. Based on the identified characteristics, we derive implications for an efficient organization of research. We show how scientists' incentives should be structured to elicit optimal research efforts and direction, whether research directions should be set at a centralized or decentralized level, and whether the organization of research should be through external competitive grants or program and institutional funding.

The Changing Structure of Incentives for Agricultural Research

Some dramatic changes have taken place in the funding of agricultural research in the United States since establishment of the U.S. Department of Agriculture, the founding of the land-grant college system under the Morrill Act of 1862, and the institution of agricultural experiment stations under the Hatch Act of 1887.

Displacement of Federal Funding by State Funding. In 1887, when the state agricultural experiment station (SAES) system was first given formal federal funding by passage of the Hatch Act, at least 82 percent of the funding was from the federal government. This share dropped dramatically to 65 percent in 1900, 25 percent in 1920, 29 percent in 1960, and 26 percent in 1990. As the share of federal support has declined, the share of state support has increased. The state funded share of SAES budgets increased from 20 percent in 1900 to 46 percent in 1920 and 58 percent in 1960. Since then, the state share of funding has decreased somewhat to 55 percent in 1980 and 1990, and further to 50 percent in 1995.

An important point about implementation of state funding was that it was provided through institutional block grants or program grants to agricultural experiment stations or land-grant universities, thus leaving the setting of directions and research program implementation to local land-grant or experiment station authority (Huffman and Evenson). A major force behind the increase in state funding was the requirement instituted in 1935 of matching regular federal funding with other, including state, funding. To receive regular USDA funding of the SAES, states were required to match federal funds. An important effect of this requirement was to provide long-run diversification in the SAES funding portfolio, which generated a very diversified public agricultural research system compared to other countries (see Huffman and Just 1999).

Displacement of Regular Federal Funding by Competitive Grant Programs. While funding for the USDA has continued to be essentially all from the federal government (USDA), the composition of the funding and mechanism for allocating federal funds to the SAES system have changed (Huffman and Just 1999a; Huffman and Evenson, pp. 21-23; Alston and Pardey, Ch. 2; Committee on the Future of the Colleges of Agriculture in the Land-Grant University System, Ch. 6). Historically a legislated formula for allocating federal appropriations to the SAES system was used. Initially all states received equal appropriations, but the formula was modified over the period 1935-55 to depend on each state's share of total U.S. farm population and total U.S. rural people.

After strong encouragement from the National Research Council, the USDA initiated a Competitive Grants Programs to finance a small share of public agricultural research in 1977. With serious federal budget deficit problems beginning in the 1980s, public pressure mounted to increase scrutiny of the efficiency and social usefulness of all public expenditures. An outgrowth of pressure has been greater interest in and emphasis on priority setting at the federal level. Arguments were advanced that SAES formula funding did not adequately reward productivity (or penalize non-productivity). One response was a substantial increase in funding for the National

Research Initiative (NRI) in 1986. Competition for NRI grants is open to all public and private researchers.

In 1900, virtually all of the 64 percent of SAES funding from the national government came in the form of USDA formula funds. Within regular federal appropriations, there has been a significant reduction in Hatch, Regional Research, and other non-grant or “formula funds” from 20.4 percent in 1960 to 9.5 percent in 1996. Concurrently, competitive and special grant funds have increased from zero in 1960 to 2.6 percent in 1996 (Huffman and Just 1999a; USDA). Hence, the funding of agricultural research has clearly tended away from regular or formula funds toward competitive grant funding.

Increased Private Funding and Public-private Cooperation. Increasingly, in the midst of budget crises, public agricultural research scientists have been encouraged by administrators to pursue nontraditional sources of funding such as non-agricultural agencies, private corporations, and commodity groups. Over the past two decades, SAES scientists in the U.S. have turned increasingly to non-regular federal and private sector sources. In 1980, the share of SAES system funding coming from nontraditional federal government sources was 11 percent. Some of these funds was distributed by the USDA through contracts and cooperative agreements. The rest was distributed through competitive grants from the National Institutes of Health, the U.S. Agency for International Development, the National Science Foundation, the U.S. Department of Health and Human Services, the Public Health Service, and other agencies primarily by competitive grants. This share increased to 12 percent in 1990 and 15 percent in 1995 (USDA).

Public agricultural scientists are increasingly being encouraged to obtain funding from private corporations and producer groups, including cooperatives. The private sector share of

SAES funding was 7.5 percent in 1960, and increased to 9.2 percent in 1980 and 14.3 percent in 1996 (Huffman and Just 1999a).

Summary. This brief account reveals that SAES funding has become increasingly diversified first to state as well as federal sources, then to non-agricultural government sources and the private sector. As this change has taken place, the traditional formula allocation mechanism of both federal and state governments has been increasingly displaced by competitive grant funding both from the USDA as well as other federal agencies and by the private sector.

Risky Production, Asymmetric Information, and the Principal-Agent Problem of Academic Research

To understand the implications of some of the recent trends in the organization of agricultural research and the potential insights offered by principal-agent theory, R&D must first be recognized as a production process that has unusual attributes relative to the production and marketing of industrial goods.

Key Attributes of Research. First, the R&D payoff is most accurately described as the "best" of scientists' outputs, rather than their total output. Second, the research production process is subject to a large amount of ex ante uncertainty. No target discovery may occur, a poor discovery may occur, or a great discovery might occur. Furthermore, unanticipated discoveries frequently occur. Hence, payoff or value of a research project is unknown at the outset of the project and output/quality is non-contractible. Third, asymmetric information exists on scientists' effort. The scientist has much better information about how he allocates his effort and on his research ability than the research administrator. Hence, it is impractical for a research administrator to monitor the effort of scientists fully. Furthermore, given ex ante uncertainty in the research production function, it is impossible for a research administrator to accurately infer effort from observed output/quality. Hence, a moral hazard arises in contracting on scientists' effort because the administrator cannot verify that scientists' efforts have met any agreed upon contract terms. Fourth, administrators are less risk adverse than scientists because they manage a much larger portfolio of projects. Each scientist may have one or two projects per period, but a research administrator may have dozens or hundreds of scientists in his organization. With different attitudes toward risk between administrators and scientists, potential inefficiencies arise when scientists are expected to bear a large share of research risk.

Building on prior research by Holmstrom, Levitt, and Gibbons, principal-agent theory is used to provide insights on efficient incentive contracting within an organization and across organizations in an environment where contracts cannot be enforced by the courts. This principal-agent model is able to accomplish this because the incentives are developed in a model where the joint surplus of the research administrator (the principal) and the scientist (the agent) is maximized, i.e., the optimal contract is incentive compatible in the sense that it is in the best private interest of both the research administrator and scientist to voluntarily fulfill the contract. This means not only that there is no need for court enforcement of optimal contracts but also that monitoring by the research administrator of the scientist's effort is unnecessary and unproductive.

Modeling Research Incentives with Uncertain Payoffs. Before assessing implications of recent trends in agricultural research, we sketch the basic model. First, the research administrator is assumed to observe the research payoff at the end of a project, to compensate scientists for their effort, possibly with a compensation package including a fixed salary and a performance incentive, and to be risk neutral about R&D payoffs.[1] For the purpose of this paper, a research project is an attempt to develop a particular innovation or a fixed term contract to conduct research in a particular area. The administrator's objective is to maximize expected R&D payoff net of scientists' compensation.

Second, scientists are assumed to obtain utility from income, disutility from effort or work, to be risk averse, and to have a reservation utility. More specifically, each scientist (denoted by the subscript i) is assumed to have a quadratic cost of effort, $c_i(e_i) = .5 k_i e_i^2$ (which generates a positive-sloped effort schedule with respect to compensation), to have constant absolute risk aversion N_i, to have a fixed certainty-equivalent reservation utility (μ_i), and to choose effort on research to maximize individual expected utility subject to attaining at least his reservation utility.[2]

Third, each scientist is assumed to work alone (to avoid team or easy-rider problems) and to undertake only one project per period that produces exactly one indivisible unit of output, but research quality is variable depending on his effort. Hence, the production function for quality has one variable input, the scientist's effort. With productivity for doing research differing across scientists, the marginal product of effort differs across scientists. Because of the highly uncertain nature of research, the production function for research is stochastic, having a scientist-specific random component ϵ_i and a common institutional component δ. The common shocks might represent unanticipated bureaucratic or scientific problems or unanticipated advances in the public stock of knowledge. Hence, the production function for research quality, which is the payoff to the principal or administrator, is[3]

(1) $$y_i = a_i e_i + \epsilon_i + \delta$$

where y_i is quality of research produced by scientist i, e_i is scientist's effort, and a_i is the expected marginal product of the scientist's effort. Differences in a_i across scientists reflects scientists' abilities for research (e.g., creativity, efficiency of mental processes, work routine — see Ladd 1987), organizational aspects of the research environment (e.g., bureaucratization of procedures), and the available stock of relevant public knowledge.[4] Each of the stochastic terms in the payoff function are assumed to have a zero mean and constant variance, σ_i^2 and σ_δ^2, respectively; and for simplicity of presentation, ϵ_i and δ are assumed to be uncorrelated. The variance of the research payoff is the summation of the two variances, $\omega_i^2 = \sigma_i^2 + \sigma_\delta^2$.

In order to provide penetrating insights on incentives, we assume that scientist's effort, e_i, is the only source of asymmetric information. It is unobservable to the research administrator but known to the scientist. Research quality, y_i, is assumed to be observable to both the administrator and scientist but only at the end of the project. We permit more than one scientist to work independently on identical research projects, but only the highest quality output contributes to the administrator's R&D payoff. This might arise through the publication process where an editor publishes the "best" paper on a topic given that it adds significantly to the state of knowledge, or through farmers using only the crop variety or animal breed that has the "best" anticipated performance.

Optimal Compensation of Public Research Scientists

An important research policy question is: What is the optimal scientist compensation scheme and how does it depend on characteristics of scientists, research projects and the research environment? To convey some basic results about optimal compensation and the associated R&D payoff, we initially consider contracting between a research administrator (or funding agency) and one scientist. According to principal-agent theory, when contracting is repeated many times and the agent has discretion in actions including the level and timing of effort, the structure of the optimal pay scheme is linear in the observed principal's payoff (Holmstrom and Milgrom; Levitt). Consider the two part compensation scheme: (i) a guaranteed payment or salary, α_i, that is independent of the observed R&D payoff, and (ii) an incentive payment that amounts to a positive share, β_i, of the observed R&D payoff,

(2) $w_i = \alpha_i + \beta_i y_i$.

A larger β_i implies a "higher powered" incentive scheme. Substituting equation (1) into (2), the structure of this pay scheme is linear in the scientist's effort,

(3) $w_i(e_i) = \alpha_i + \beta_i a_i e_i + \beta_i \varepsilon_i + \beta_i \delta$.

Equation (3) depicts how ex ante uncertainty in the research production process is transmitted into ex ante income uncertainty for the scientist. From equation (3), the expected wage conditional on effort is $E(w_i) = \alpha_i + \beta_i a_i e_i$ and the wage variance is $V(w_i) = \beta_i^2 \sigma_i^2$.

Under the assumption of constant absolute risk aversion for utility of the scientist, his expected utility can be expressed in terms of certainty equivalence as

(4) $E[U_i(e_i)] = \alpha_i + \beta_i a_i e_i - .5 k_i a_i^2 e_i^2 - .5 \phi_i \beta_i^2 \sigma_i^2$.

The research administrator's payoff net of scientist's compensation is $\Pi_i = y_i(e_i) - w_i(e_i) = (1-\beta_i) a_i e_i + (1-\beta_i)(\varepsilon_i - \delta_i)$. Therefore, the expected net payoff is

(5) $E\Pi_i = (1-\beta_i) a_i e_i - \alpha_i$

Clearly if $0 < \beta_i < 1$, the expected net payoff of the research administrator is positively related to a scientists' effort, e_i, (and ability, a_i). However, the administrator's expected net payoff is negatively related to the size of wage guarantee or salary of the scientist, α_i.

The administrator chooses the parameters of the incentive scheme, α_i and β_i, to maximize his expected net payoff subject to the constraint that the scientist chooses effort to maximize his expected utility and that he attain at least his reservation utility while contracting with the principal, i.e.,

(6) $$\max_{\alpha_i,\, \beta_i} \; [(1-\beta_i) a_i e_i - \alpha_i] \qquad \text{s.t.}$$

(7) $$\max_{e_i} \; (\alpha_i + \beta_i a_i e_i - .5 k_i a_i^2 e_i^2 - .5 \phi_i \beta_i^2 \sigma_i) \qquad \text{and}$$

(8) $$\alpha_i^* + \beta_i^* a_i e_i^* - .5 k_i a_i^2 (e_i^*)^2 - .5 \phi_i (\beta_i^*) \sigma_i^2 \geq \mu_i .$$

Note that conditioning the administrator's problem insures that the scientist chooses a privately beneficial effort rate when faced with the compensation scheme (i.e., incentive compatibility), and will be offered a compensation package that he will accept (i.e., meets his reservation constraint). In this model, it is unproductive for the administrator to offer a compensation scheme that the scientist rejects because the administrator's expected payoff is zero, i.e., $Ey_i(0) = 0$.

Because research risk is independent of effort in this model, the optimization problem in (6)-(8) can be solved sequentially. First, the optimal solution to the scientist's decision on effort in equation (7) is

(9) $$e_i^* = \beta_i a_i / k_i$$

which depends positively on the scientist's marginal product of effort (a_i) and inversely on his marginal cost of effort. Second, substituting equation (9) into (6) and (8) and choosing α_i and β_i, Kuhn-Tucker conditions (or direct examination) reveal a boundary solution in (8), $E[U_i(e_i^*)] = \mu_i$, implying:

(10) $\alpha_i^* = \mu_i - .5\beta_i^2(p_i - r_i)$

where $p_i = a_i^2/k_i$ is a scientist-specific "research productivity index" and $r_i = \phi_i\omega_i^2$ is a scientist-specific "research risk index." Substituting (10) into (6) and (8) and maximizing with respect to β_i reveals the optimal scientist performance incentive,

(11) $\beta_i^{**} = p_i/(p_i + r_i)$

which, when substituted into (10), gives the globally optimal guaranteed payment or salary,

(12) $\alpha_i^{**} = \mu_i - .5p_i^2(p_i - r_i)/(p_i + r_i)^2.$

With this optimal pay scheme, some notable results follow. First, the joint (certainty equivalent) surplus of the administrator and scientist is maximized and both have an incentive to fulfill the contract. Second, the administrator compensates the scientist for his effort at a rate that provides partial insurance against income risk. With asymmetric information on the scientist's effort, the administrator does not provide full-income insurance to the scientist because that would provide weak incentives for effort, most likely leading to shirking. Third, the salary or guaranteed component of a scientist's compensation is positively related to his reservation utility μ_i, but his reservation utility has no impact on the incentive component. Fourth, an increase in the research risk index r_i decreases the optimal incentive, β_i^*, and the optimal salary or pay guarantee is increasing in the research risk index if and only if $3p_i > r_i$, which we argue later to be plausible.[5] Thus, low research risk, low scientist risk aversion, low cost of scientist's effort, and/or high marginal research productivity is sufficient to cause the salary or guaranteed payment to increase in research risk. If research is infinitely risky (i.e., $\omega_i^2 \to \infty$, $r_i \to \infty$), then $\beta_i^{**} = 0$, and the optimal pay scheme is a fixed salary equal to the certainty-equivalent utility (i.e., $w_i = \alpha_i^{**} = \mu_i$). In this case, the administrator optimally bears all the risk because he is risk neutral and less risk averse than the scientist. Thus, an increase in research risk, r_i, decreases the importance of the incentive relative to the salary or guarantee. Fourth, an increase in the research productivity index, p_i, increases the optimal incentive, and it also increases the optimal salary or guarantee if research risk is large relative to the scientist's research productivity.[6] However, if research risk is small relative to scientist's research productivity, the salary or guarantee will be decreasing in scientist's research productivity.

Expected Benefits Under Optimal Incentives. To obtain further insights from our principal-agent model of optimal research incentives, note the optimal effort of scientists is

$$(13) \qquad e_i^* = a_i p_i / [k_i (p_i + r_i)],$$

the expected compensation of the scientist net of his cost of effort is[7]

$$(14) \qquad E[w_i(e_i^*) - c_i(e_i^*)] = [.5 p_i^2 r_i + \mu_i (p_i + r_i)] / (p_i + r_i)^2,$$

(which is equal to the reservation wage plus the risk premium) and the expected R&D payoff for the research administrator net of the scientist's compensation is

$$(15) \qquad E\pi_i(e_i^*) = .5 p_i^2 / (p_i + r_i) - \mu_i .$$

If the scientist is risk neutral (i.e., $\rho_i = r_i = 0$), then equation (13) becomes a_i/k_i, equation (14) becomes $k_i \mu_i / a_i^2$, and equation (15) becomes $.5p_i - \mu_i$. With asymmetric information on the scientist's effort, the scientist's risk-averse attribute reduces the administrator's payoff and the scientist's effort from the first-best outcome.[8] Some net R&D payoff (and research quality) is foregone by the administrator in partially insuring the risk averse scientist against risk. Furthermore, given the scientist's reservation wage μ_i, the scientist must also receive higher net compensation because he must be paid to bear his part of the risk. Because he is more risk averse than the administrator, the risk borne by the scientist is inefficient risk bearing. Hence, only "second-best" resource allocation is attainable.

Equations (13), (14), and (15) reveal that a risk-neutral research administrator is better off contracting with a scientist that has low scientist-specific research risk (i.e., F_i^2 is small) and low risk aversion (i.e., small N_i). The reason is that the scientist requires less compensation for bearing risk and exerts more effort. Differentiating $EA_i(e_i^{(})$ with respect to p_i also reveals, not surprisingly, that a research administrator is better off contracting with a scientist that has higher research productivity.[9]

Differentiating equation (14) with respect to p_i, the scientist receives larger expected net compensation when his marginal product of effort is higher (a larger a_i) and/or his marginal cost of effort (k_i) is lower.[10] However, the effect of risk aversion on expected scientist compensation is not clear. Differentiating (14) with respect to r_i reveals that $M E[w_i(e_i^{(}) \& c_i(e_i^{(})]/M r_i > 0$ for certain only if $p_i > r_i$.[11] Thus, if his research productivity is low, the scientist fares better with higher research risk and risk aversion. But if his research productivity is high, the scientist may be better off with lower research risk and risk aversion. Perhaps, the result that scientists who have low marginal or opportunity cost of effort (and possibly low research risk) earn greater compensation than others is surprising, but it is explained by the fact that more R&D payoff is traded away for purposes of risk avoidance by those with high opportunity cost of effort (and high risk premiums). We note that this phenomenon may not be observed in reality because administrators tend not to hire or grant tenure to low-productivity scientists.

Some Implications for Funding Mechanisms

The attributes and incentives of alternative funding mechanisms, e.g., external peer-reviewed competitive grants, incentive contracts, and block or program grants are different in ways that affect scientists' effort, research quality, and efficiency of resource allocation across all academic programs. This section examines each of these funding mechanisms heuristically from the perspective of the model developed in the preceding section.

Peer-reviewed Competitive Grants Programs. From the perspective of the optimal incentive contracting model, the peer-reviewed competitive grant mechanism is an inefficient contract. First, the funding/granting agencies attempt to operate independent of academic institutions but impose significant externalities on the activities of scientists in academic institutions. Resources are not allocated nor are incentives set to maximize the joint surplus of the external funding agency (principal) and the scientists of academic institutions (agents), taking account of the riskiness of research and attributes of scientists. For example, when external funding agencies ask for research proposals, the cost of proposal writing, which uses scarce resources, is usually not funded so scientists' efforts going to proposal writing are diverted from other research projects reducing their expected payoff, from instruction/teaching activities which reduces the expected achievement of students, or from leisure which is detrimental to their health and personal life of scientists. Thus, competitive grants programs are distortionary and generally impose negative externalities on scientists other activities.

Applying the Coase theorem, socially optimal resource allocation decisions cannot be attained with externalities when the affected organizations/businesses attempt to make decisions independently (unless appropriate taxes or subsidies are imposed). Instead the organizational device to achieve socially efficient incentives is one that views the affected organizations/

businesses as one combined decision-making unit (also see Cornes and Sandler, p. 86-89). Although research proposal writing is a legitimate research activity, proposal writing for new projects should not distort scientists' effort going into existing projects, teaching obligations or leisure time. An important economic issue is what is the optimal amount of resources to be allocated to proposal writing compared to conducing research, writing reports, and preparing manuscripts for publication. We hypothesize that in an organization of science large enough to internalize all externalities, research proposal writing and evaluation would receive considerably less emphasis than when science is primarily funded by external peer-reviewed competitive grant programs.

Second, the peer-reviewed competitive grant system places primary emphasis on the quality of the research proposal which is imperfectly correlated with the uncertain research payoff of the project. For most legitimate research proposals, nobody knows what can be discovered, and the principal-agent literature emphasizes that with asymmetric information the scientist or agent has superior information. Granting agencies, in contrast, proceed under the assumption that other scientists, frequently not even working on closely related research problems, have superior information about the potential payoff of research projects (U.S. GAO). Thus, these "peer" reviews and panels are frequently ill-positioned to accurately judge quality and potential, and when they are well informed, they tend to be too cautious in their assessments of research methods and potential. They also tend to impose too much homogeneity of approaches which reduces the diversity of sampling from the discovery distribution, or to require large amounts of uncompensated preliminary research results.

Third, granting agencies determine the size of the award up front based on the proposal even though at that time nobody knows what can or will be discovered or what unexpected obstacles and delays may be encountered. Whether research quality is high or low, the scientists receives the same award. This reduces the scientist's incentive to devote effort toward uncertain discoveries, even if there is some chance of seeking later funding through the same granting agency.

Fourth, peer-reviewed competitive grant programs shift an unduly large share of research risk to scientists, who are in an inferior position for risk bearing. When these agencies do not fund proposal writing and only a fraction of proposals receive funding, scientists bear significant institutional risk of research. Furthermore, even if a scientist is successful in getting a proposal funded, the tradition of funding agencies is to cover significantly less than full cost of the research project. Hence, with competitive grant funding, scientists face uncertainty about being able to obtain enough resources to complete a project. Even for a "funded scientist," projects may be prematurely terminated or delayed indefinitely. For scientists who write proposals that do not get funded, projects are also terminated prematurely or delayed.

Within the principal-agent model of research incentives, the possibility of premature termination of projects greatly weakens scientists' incentive for effort, including proposal writing, and generally lowers the quality of research relative to optimal incentive contracting (see Levitt and Snyder). Thus, the principal-agent model predicts low quality research proposals for external competitive grants programs, especially when average awards are small. In fact, a common complaint of external granting agencies is that a large share of the proposals they receive are of poor quality.

Fifth, given the unusual attributes of research, the most efficient resource allocation is attainable when the principal (funding agency) and agents (scientists) are engaged in a long-term relationship. In a long-term relationship, problems stemming from asymmetric information are reduced because the administrator learns more about each scientist's ability and other performance attributes and fine-tunes incentives to the riskiness of the research and attributes of the scientist.

Thus, external granting agencies are in an awkward position for determining expectations about the length (and amount) of funding for scientists' research. To the extent that peer-reviewed competitive grant programs do not guarantee short- or long-term funding to everyone submitting a proposal, scientists' incentives for effort on proposals and funded projects are weakened. If funding of a scientist with a competitive grant is a one-time event, the expected payoff is often quite low. However, to the extent that funding agencies guarantee "renewal of successful" projects, they become less competitive and similar to a program funding mechanism. In fact, the tradition of the National Science Foundation has been one of extensive competition where the expected size of awards is small, but little competition or emphasis on the quality of research proposals where the expected size of the award is large. These latter funds have been allocated largely to scientists who have compiled long-term successful research programs in the area where a large grant is to be made (see U.S. GAO for details).

Although peer-reviewed competitive grant programs claim to attract the best talent to their programs, this seems largely to be a subjective evaluation because little objective examination has been conducted (U.S. GAO; Chubin and Hackett). Even if these programs attract more able scientists, the model of this paper suggests that the relevant issue is whether the increase in ability of funded scientists is large enough to offset the weakened incentives for effort toward discovery and the effect of imposing risk on scientist relative to alternative funding mechanisms. These latter attributes of grant programs tend to reduce scientists' effort and research quality possibly offsetting any gain in attracting more able scientists relative to alternative funding mechanisms that have more efficient incentives directed toward optimal effort.

Incentive Contracting with Outsiders. Research contracts between scientists and external funding agencies for research seem to have considerable potential but also face significant problems due to asymmetric information, especially in a short-term relationship. The model of this paper has direct and important implications about how these contracts should be constructed. First, the optimal contract should contain "quality-based" incentives rather than "cost-based" incentives. The incentive for quality encourages effort toward greater payoff when the payoff is uncertain. Cost-based incentives tend to destroy economic efficiency just as in standard revenue maximization models of production. Additionally, cost-based incentives encourage hiring second-rate scientists to carry-out research while first-rate scientists concentrate on raising further research funds. As a result, the expected research quality and ultimate research payoff is lower than if first-rate scientists' time is focused on carrying out the research.

Second, the payoff of the project should be defined so that it provides an indication of the broad nature of the desired discovery or innovation but is otherwise vague about the procedures, channels, or routes to be pursued. This provides scientists with many options for attaining research success thus reducing research risk when the route to a successful discovery is uncertain.

Third, the contract should be structured to compensate scientists for effort with optimal risk sharing. This means that contracts should be tailored to the riskiness of the research project.

With asymmetric information about scientists' attributes, however, it may be difficult to design contracts that also take complete account of scientists' performance and preference attributes that go into optimal incentive contracting (e.g., marginal cost of effort, reservation utility, and degree of absolute risk aversion). This is a typical weakness of external contracting when contractors do not have a history of interaction with scientists as in the following case. Overall, quality-based incentive contracts for research may prove to be a relatively efficient funding mechanism when the goal of an external funding agency is to "steer" or "give direction" to research (Olson) as long as differences among the scientists so attracted are not great.

Program, Block Grant, or Formula Funding. Program, block grant, or formula funding of agricultural research institutions by national and state/provincial governments has traditionally been an important funding mechanism (Huffman and Just 1999a, 1999b; Huffman and Evenson). In the U.S., much of this research has been and is conducted in state agricultural experiment stations. These institutions are part of land-grant universities where administrator-scientist relations are manifest in hiring, promotion, and tenure policies. However, the research administrator-scientist relationship is generally a long-term one and research administrators make long-term commitments to fund part or all of scientists' time/effort and provide complementary research resources, e.g., office space, research assistants, secretarial services, research equipment, supplies, etc. Traditionally, scientists have prepared short research proposals on SAES time for projects of 3-5 years in length with the possibility of extensions, renewals, and/or revisions. Over the past century, these proposals have primarily been reviewed for consistency with institutional objectives and needs. Aside from scientists' time/effort covered by the agricultural experiment station, the commitment of other resources has generally been related to importance of the project, the experience and productivity of the scientists, and the financial status of the SAES budget. Publications, trained graduate students, other scholarly outputs, and short annual progress reports are expected from these projects. Thus, with formula and program-funded research, relatively few resources are allocated to proposal writing and internal evaluation relative to external competitive grant programs. Also, administrators have not seriously monitored research efforts of individual scientists. Rather, the primary emphasis has been on measuring and rewarding research payoffs. As a result, first-rate scientists' time is allocated directly to the research activity.

Research productivity is typically measured by external publications in professional journals and books, patents, breeders' rights, doctorates trained, etc. Since the same institution is employing the scientist for both research and instructional and possibly extension services, few non-internalized externalities exist across scientists' university activities.

The SAES administrators are in an advantageous position to select for their research staff scientists who seem to have attributes that lead to large research payoffs because recruitment can focus on the attributes of scientists rather than attributes of an immediate short-term research project. They can then fine-tune incentives in a way that is consistent with the incentive contracting model presented in this paper. The typical interviewing process not only attempts to identify highly productive scientists but also scientists who have low research risk, e.g., high probability of getting tenure. The tenure review process also appears to be an effort to weed out scientists of low creativity/productivity and high risk.

Consistent with the model of this paper, incentive payments have been an important implicit component of scientist compensation contracts. While one-shot ex post incentive payments have not been typical, permanent salary increments (merit increments) based on annual and periodic promotion reviews of past performance have been a fundamental part of scientist compensation schemes. In effect, offering incentives in the form of permanent salary increments rather than one-shot payments has provided administrators a way of paying large implicit incentive payments with limited short-term budgets.

The extent to which administrators have sought initially scientists who have low opportunity cost and low reservation utility is less clear but without doubt administrators in the traditional SAES system have paid higher salaries to scientists who have generated higher offers elsewhere and have, at times, offered higher salaries to attract scientists into specific fields that are hard to fill, possibly because those fields have been perceived as more risky. Notably, the typical SAES location in small, inland towns limits high opportunity costs caused by private alternatives in large cities and coastal locations. Also, university salaries are typically low relative to private sector alternatives for similar education and experience, which suggests that the university salary structure leads to self-selection of individuals into academic research who do not have extremely high reservation utilities or expectations for compensation.

Arguably, administrators are more interested in high productivity and in low opportunity costs and low risk aversion. We note, however, that scientists' productivity and risk aversion tend to be highly correlated (positively and negatively, respectively) with reservation utility (alternative salary opportunity) and opportunity cost (wages earned by converting recreation time into consulting activities). Thus, the process of identifying scientists with high productivity, low risk aversion, low reservation utility and low opportunity cost may be difficult and result in the most important of these characteristics (e.g., productivity) dominating the choice.

Overall, viewed form the principal-agent model of this paper, we conclude that the traditional functioning mechanism of SASE formula and program funding from federal and state governments parallels closely the characteristics of a socially efficient funding mechanism for attaining high value research payoffs compared to other funding mechanisms.

With the recent decline in traditional sources of SAES funding and current fad of activist research management, some directors have chosen to implement new research policies that affect the size of institutional research risk faced by scientists. Such policies are characterized by abruptly termination of some research projects, fostering more competition for the use of federal and state formula and program funds thereby reducing the amount and length of expected funding for each scientist and project, eliminating funds for research assistants, and more directly managing current expenditure of funds. In the principal-agent model of research incentives, these policy changes imply an immediate increase in the institutional riskiness of research. An increase in institutional riskiness of research, other things equal, implies a reduction in scientist's effort, a reduction in the expected R&D payoff of the SAES director, and a reduction in the expected net compensation of scientists. Hence, such policies appear to be counterproductive and to be a step backward from earlier SAES management policies that were less interventionist.

Conclusions

This paper has presented an overview of the agricultural research establishment directed toward delineation of important alternatives in agricultural research funding and specification of a theoretical model of related agricultural research management issues. Then a model of optimal agricultural research management is presented emphasizing the ex ante uncertainty of research payoffs. The model draws heavily on previous work in management of innovative processes generally but adds the important feature of heterogeneous scientist ability. Results reveal that the current movement toward external grant funding rather than formula/program funding of SAES research and more direct intervention in the research process by administrators may be counter-productive compared to procedures which focus primarily on incentive compatible reward structures that emphasize research productivity of value to the SAES. The reasons are that, in moving from formula/program funding to external grant funding, (i) scientist time is taken away from productive activities and allocated to proposal writing and evaluation, (ii) cost in the form of a proposed budget rather than research output is compensated, (iii) quality proposals rather than quality research output is rewarded even though the two are imperfectly correlated, (iv) compensation is determined ex ante necessarily eliminating quality from the incentive scheme, (v) the riskiness of research is imposed unduly on scientists, (vi) the highest quality scientists tend to focus more on grant-proposal writing leaving the actual research to scientists with less experience, ability, and/or productivity, and (vii) peer review committees sometimes make erroneous judgements about project potential and frequently impose narrow views on research approaches thus eliminating the benefits of sampling diversity.

This paper is apparently the first to present a formalized theory of agricultural research funding. The implications for current directions in funding are significant because the share of funds allocated by apparently inefficient approaches (grants) is increasing. As this direction continues, agricultural research funds will tend to become more political and bureaucratic, which tends to reduce sampling diversity and eliminate high-risk/high-payoff projects. Typically, Congress tries also to achieve non-scientific objectives by the way national grant funds are allocated. As these objectives are superimposed on the grant-award process, the inefficient character of grant-funded research is further amplified. For example, the last round of USDA-NRI research proposals required fourteen different forms or documents in addition to the project description, references, and budget. Furthermore, each of these forms had very precise guidelines about exactly what information was to be included, the order of presentation, and exact placement on the form. This bureaucratization of research tends to screen out more creative and potentially higher payoff projects. If this direction continues, larger shares of research resources are required for overhead and more staff must be employed to shepherd proposals through the system.

Because this paper represents an initial attempt to formalize a theory for agricultural research management, more research is needed. Other aspects need to be thoughtfully examined. For example, we have not considered the possibility of (i) team research projects and how to set incentives when the contribution of individuals to team efforts is uncertain and information about individual effort is asymmetric, (ii) how to set incentives in the presence of inter-regional externalities that are imperfectly internalized by the existing SAES system even in the regional research program (see Huffman and Just 1999b), or (iii) scientists splitting their effort between research and education/outreach activities.

Endnotes

[1] A risk neutral preference for administrators can be justified by thinking of them as managing a large portfolio of projects. The assumption of risk neutrality can be modified but at significant cost in additional complexity of the presentation. Relaxing this assumption leads to little change in the basic conceptual conclusions provided scientists are more risk averse than administrators.

[2] As a utility function for scientists (the agents), we use an additively separable function which has typically been employed to simplify obtaining solutions of principal-agent models (see Mas-Colell, Whinston, and Green, pp.479-80).

[3] Note that adding a scientist-specific constant term in equation (1) unnecessarily complicates the derivation of important results while adding little in the case where the constant term is positive. When the constant is negative, as it would be with significant fixed start-up costs, simple solutions are difficult to obtain. This important topic is left for future research.

[4] While the model of this paper draws heavily on the previous work of Holmstrom and Milgrom and Levitt, it differs in the important respect whereby scientists have heterogeneous ability and employing scientists of superior ability is one of the administrator's most important avenues to success.

[5] From equation (11), $\partial\beta_i^{**}/\partial r_i = -p_i/(p_i+r_i)^2 < 0$, and from equation (12), $\partial\alpha_i^{**}/\partial r_i = .5p_i^2(3p_i - r_i)/(p_i+r_i)^3 > 0$ if $3p_i - r_i > 0$.

[6] From equation (11), $\partial\beta_i^{**}/\partial p_i = r_i/(p_i+r_i) > 0$ for $p_i, r_i > 0$; and from equation (12), $\partial\alpha_i^{**}/\partial p_i = -.5p_i[p_i^2 + r_i(3p_i - 2r_i)]/(p_i+r_i)^3 < (>)\ 0$ if $p_i^2 + r_i(3p_i - 2r_i) > (<)\ 0$ and $p_i > 0$.

[7] The expected compensation is $Ew(e_i^*) = .5p_i^2/(p_i+r_i) + \mu_i$.

[8] Note that $p_i > p_i^2/(p_i+r_i) = p_i[p_i/(p_i+r_i)]$ for $p_i, r_i > 0$.

[9] From equation (15), $\partial E[\Pi(e_i^*)]/\partial p_i = p_i r_i/(p_i+r_i)^3 > 0$ for $p_i, r_i > 0$.

[10] From equation (14), $\partial E[w_i(e_i^*) - c_i(e_i^*)]/\partial p_i = r_i[.5p_i + p_i r_i + \mu_i]/(p_i+r_i)^2 > 0$ for $p_i, {}_i > 0$.

[11] From equation (14), $\partial E[w_i(e_i^*) - c_i(e_i^*)]/\partial r_i = [.5p_i^2(p_i - r_i) + \mu_i p_i]/(p_i + r_i)^3 > 0$ for $p_i > r_i > 0$.

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