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Persistent Underinvestment in Public Agricultural Research

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Abstract

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It is often argued that public support of agricultural research is inadequate. However, the empirical papers that support this hypothesis rarely reflect formal behavioral theory capable of explaining this phenomenon. This paper presents a theory that explains underfunding, namely, that funding agencies respond too slowly to secular changes in the value of research. A model of farmer and funding agency behavior is presented, and shown to imply that actual research funding will be consistently smaller than optimal funding. The assumptions and results of the model are explained in terms of the institutional literature on public agricultural research agencies.

Introduction

A current puzzle in agricultural research policy is to explain the consistently high rates of return to publicly sponsored agricultural research. Surveys of the literature on research return finds rates of return to agricultural research in excess of 15% that are persistent over time, across research types, and across countries (Evenson et al., 1979; Ruttan, 1982a). Most rates of return exceed 35%, leading Ruttan to conclude that "it is hard to imagine many investments in either private or public sector activities that would produce more favorable rates of return (p. 241)". Recent studies continue to find high rates of return to a variety of agricultural research and extension programs. Claims of underinvestment in the U.S. are made by Bonnen (1983) and Rose-Ackerman and Evenson (1985). Davis (1981) finds high internal rates of return to U.S.

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research. Zentner and Peterson (1984) and Ulrich et al. (1986) find high rates of return to Canadian research. In India large returns to research and extension are found by Rai and Panghel (1979), Ram and Sirohi (1979), Singh and Bhullar (1979) and Singh et al. (1979); however, mixed results are obtained by Jayaraman (1979). Pinstrup-Andersen (1982) finds high rates of return for a number of countries.

The purpose of this paper is to explain more completely the persistently low levels of support given to public agricultural research. To this end a formal model of the agricultural sector with endogenous research expenditures is developed. The model exhibits behavior consistent with the observed underfunding of research. The assumptions and results of the model are related to existing descriptions of research funding processes.

Despite the preponderance of evidence indicating that publicly sponsored agricultural research has not been funded at an adequate level, there are relatively few explanations of why underfunding occurs and why it is so pervasive (Fox (1985) presents a contrary interpretation). Ruttan (1982) suggests two explanations for the high rates of return found in the United States: good research portfolio management, and excess control of funds at the state level. While good portfolio management is consistent with high rates of return, it is hard to understand why additional funds are not provided for the portfolio: this hypothesis "does not go very far in helping one to understand the underinvestment in agricultural research implicit in the high rates of return" (Ruttan, p. 254). Ruttan's second argument suggests that in the U.S., control of research funds at the state level leads to underinvestment in projects which have spillover benefits to neighboring areas because the state agency undervalues these external benefits. The argument does not explain the underinvestment in countries such as Canada which funds only 5% of its agricultural research at the provincial level (Brooks and Furtan, 1984).

Ruttan's argument about state control of funds is an example of the fragmentation hypothesis suggested by Davis (1981), Bonnen (1983), Johnson (1985) and others. This hypothesis suggests that research resources are misallocated because the research bureaucracy is fragmented and allocation decisions are made by a number of subagencies in an uncoordinated fashion. The fragmentation is complicated by the existence of discrepancies between the agency's objective and the incentives provided to administrative and other actors in the budget process (Wade, 1973a,b). For example, research administrators may place priority on personal objectives or the welfare of a particular, non-farm constituency. Recent work by De Janvry and Dethier (1985) extends the idea of fragmentation to include information costs and asymmetries. The two major categories of informational discrepancies cited are misperceptions by the researchers of the type of work needed and misperceptions by administrative agencies of the demand for innovations. It is hard to believe that researchers engaged in the "wrong" work would achieve the estimated rates of return. However, misperceptions by administrative agencies could be a significant problem. Many types of fragmentation do have an impact on research and are particular examples of the more general causes of underfunding described in this paper.

This paper models the underfunding of public agricultural research as the result of rigidities in the budget appropriation process. The optimal level of research funding is determined within a static setting. To approximate intertemporal behavior the parameters of the model are subject to a series of shocks, and a sequence of static equilibria is examined. Rigidities in the budget process prevent an immediate response to these shocks. It is shown that when the demand for the agricultural product increases or when the costs of doing research decline, then the amount spent on agricultural research is less than optimal. The optimal amount of research rises when output demand increases or when research efficiency increases. Rigidities in reallocating or increasing funds implies that appropriations will not respond immediately to the shocks. Thus actual research expenditures will lag behind optimal expenditures. This behavior is consistent with the empirical studies cited above.

The structure of the model developed in this paper is very similar to that of an induced innovation model because both have endogenously determined research expenditures (e.g. Binswanger and Ruttan, 1979). The current model differs from an induced innovation model by specifying lags in the response of the funding agency and hence allowing suboptimal research expenditures. The current model is also different in focus. The induced innovation literature is concerned predominantly with models exhibiting behavior consistent with observed patterns of technical change. This paper is concerned predominantly with developing a model that is consistent with the observed patterns of public research funding.

The paper is structured as follows. The next section develops a simple static model of research funding. The section after that uses comparative statics to derive implications of the model regarding actual and optimal levels of support. The primary finding is that the realized levels of support will be smaller than the optimal levels. A sequence of comparative exercises shows that this underfunding can persist over time. This finding is interpreted in the context of the literature on the nature of public research institutions. The last section contains conclusions and suggestions for further work.

A model of research appropriations

This section develops a model of research appropriations based on agricultural supply and demand. The actors in the model are the farmers and the research funding agency. Farmers maximize profits, taking prices and technology as given. The funding agency supports research that reduces production costs. Reductions in production costs are represented by a rightward shift of the marginal cost curve. Research is supported at the level that minimizes the sum of production and research costs. The model is solved in a static framework to determine agricultural production, the price of output, and the choice of technology. Equilibrium occurs at the levels of price, quantity and technology that simultaneously clear the output market and solve the funding agency's minimization problem.

There are n farmers in the economy. In the sequel we shall assume that n is relatively large. Each farmer uses capital and labor to produce a single agricultural output. The representative farmer has the cost function

$$C(q,w,r,a), \tag{1}$$

where q is the quantity of output, w is the wage rate, r is the capital rental rate, and a is a parameter representing the technology level. An increase in the value of a will represent technical progress. The following assumptions are maintained:

$$\begin{aligned} &C_q > 0,\ C_{qq} > 0 \\ &C_a < 0,\ C_{aa} > 0 \\ &C_{qa} < 0 \end{aligned} \tag{2}$$

The first two assumptions imply that total costs increase as output increases, and that the production technology exhibits decreasing returns to scale. The second set of assumptions implies that an increase in the technological parameter a decreases costs, but at a decreasing rate. The last assumption states that technical progress decreases the marginal cost of production.

Factor supplies are assumed to be perfectly elastic at rental rates r and w. This assumption is consistent with an exogenous determination of capital and labor market clearing conditions, perhaps in the manufacturing sector. Relaxing this assumption to allow for upward sloping factor supply curves complicates the analysis without changing the results, and hence the simpler assumption is retained.

It is assumed that the agricultural industry is competitive, so that each farmer will produce at a level that equates marginal cost with price. This condition is represented by eqn. (3)

$$P = C_q(q,w,r,a) \tag{3}$$

Aggregate production is $nq^*(P)$ where q^* is the value of q that solves eqn. (3).

Demand for the agricultural good is given by

$$Q = D(P,\delta) \tag{4}$$

where δ is a shift parameter that represents additional factors affecting agricultural demand. Examples of such factors are income and population. Increases in δ increase the quantity demand at each price; that is, $\partial D/\partial\delta > 0$.

For a given technology the output market will clear when $nq = Q$. Thus the output market equilibrium conditions are eqn. (3) and

$$nq = D(P,\delta) \tag{5}$$

Thus far the model is a standard textbook model of an individual market with fixed factor prices and fixed technology. We now examine the model when the research agency conducts research that will change the farmer's choice of technique(s).

The funding agency supports research that introduces new, cost-saving techniques of production. The introduction of these techniques increases the value of the parameter a, which shifts the cost function to the right. The research cost of achieving a certain level of technology is $R(a,\rho)$. The parameter ρ represents nonresearch factors that affect the research cost. An example of such a factor is the human capital of farmers; certainly the cost of developing farm management software for microcomputers is lessened by increases in human capital. It is assumed that increases in ρ decrease the cost of doing research, so that $R_\rho < 0$. It is further assumed that the production of new techniques exhibits decreasing returns to scale, so that $R_a > 0$ and $R_{aa} > 0$.

The funding agency solves the following minimization problem:

$$\min_a nC(q,w,r,a) + R(a,\rho) \tag{6}$$

Thus the agency minimizes the total amount of societal resources devoted to agricultural production of amount q by each of n farmers. The societal resources consist of the productive inputs as well as the research expenditures.

The objective function in (6) is consistent with the goal of maximizing social surplus in the agricultural market when research costs are considered to be part of the cost of production. Actual funding processes may reflect not just social surplus but also potential transfer to certain constituent groups. While this phenomenon is not considered part of the objective function in this model, it is discussed in some detail below. Political power and transfer payments are analyzed formally by Becker (1983), who develops a theoretical model in which the government merely responds to interest group power and preferences. For applications to agriculture see Huffman and McNulty (1985), Rose-Ackerman and Evenson (1985), Huffman and Miranowski (1981) and Brooks and Furtan (1984).

The first order condition for the funding agency is

$$R_a(a,\rho) = -nC_a(q,w,r,a) \tag{7}$$

The left-hand side is the marginal research cost of increasing the technology level. The right-hand side is the marginal benefit of increasing the technology level, represented in terms of production cost savings. At an optimum marginal costs equal marginal benefits.

Equilibrium is achieved at that price, quantity, and technology level that clear the output market and solve the funding agencies minimization problem. More formally, an equilibrium is a triplet (P^*,q^*,a^*) such that eqns. (3), (5) and (7) are satisfied. From the equilibrium solution we can determine the optimal level of research expenditures, R^*.

Actual versus optimal research expenditures

This section introduces a rigidity into the research funding process. The rigidity is modeled formally by assuming that at time t the research funding agency makes decisions based on parameter values from time $t-1$. Interpretations of this assumption are presented at the end of the section. The implication of this assumption is that actual research expenditures will adjust towards the optimal level only after a time lag. If the optimal level increases over time then actual expenditures will consistently be too small. This is exactly the behavior found by the rate of return studies discussed above.

The following assumption is made:

$$Cqq(Raa+Caa) > Cqa^2$$

This is a condition on the curvatues of the production and research cost functions, and is a sufficient condition for $\mathrm{d}R^*(a,\rho)/d\rho > 0$; that is, it guarantees that research is a normal good. This assumption also eliminates other pathological behavior: it insures that $\partial P^*/\partial\delta > 0$ so that an actual shift in demand increases equilibrium price (this might not be the case if the research response to $\mathrm{d}\delta$ greatly shifted the supply curve down).

The basic result is provided by the following comparative statics exercise.

Theorem 1: The optimal level of research expenditures R^* will increase if δ increases or if ρ increases (or both).

An increase in δ implies an outward shift of the agricultural demand curve. Hence any cost-saving techniques introduced by research will affect a greater quantity of output, increasing the marginal value of the research. In order to maintain equilibrium more money will be spent on research until the marginal value of research falls to equal marginal cost once again. An increase in ρ means that research has become more efficient at inducing profitable technical change. This also means that the marginal return to each dollar spent on research increases. Again the optimal response is to spend more money on research.

The formal proof of theorem 1 depends on manipulating and differentiating the equilibrium conditions (3), (5) and (7). Due to the straightforward but tedious nature of the mathematics this proof has been exiled to the Appendix.

The next result establishes the link between rigidities in the appropriations process and suboptimal research funding.

> *Theorem* 2: Suppose that δ increases or ρ increases. Suppose further that the research funding agency does not recognize that one or more of these conditions has occurred, so that it is solving the maximization problem (10) based on the original values of the parameters. Then research expenditures will be smaller than is optimal.

This theorem follows immediately from theorem 1. For example, suppose that the value of δ rises from δ_0 to δ_1. Theorem 1 indicates that the optimal level of research expenditures is higher when $\delta = \delta_1$ than when $\delta = \delta_0$. If the agency solves (10) taking $\delta = \delta_0$ it will be funding research at a level that is lower than optimal for the true value $\delta = \delta_1$. Similar arguments explain the theorem in the second case.

Theorems 1 and 2 indicate that optimal research expenditures increase when demand for the agricultural product increases or when the efficiency of research increases. Research funding will be suboptimal if actual expenditures do not keep pace with optimal expenditures. This will happen if the funding agency is slow in responding to increases in output demand or research efficiency. Theorem 3 indicates that consistently slow responses can lead to persistent underfunding.

> *Theorem* 3: Suppose that δ increases or ρ increases at each time t. If the research agency makes its decisions at time t based on the parameter values at time $t-1$, then at every time t research expenditures will be lower than optimal.

Theorem 3 is a generalization of theorem 2 to consecutive time periods. Under the hypothesis of theorem 3, theorem 2 can be applied to each time t to show that research is underfunded in that time period. Since this is true for an arbitrary time period, the conclusion of theorem 3 follows.

The importance of theorem 3 is that it describes research funding behavior consistent with the empirical evidence on agricultural research expenditures. It shows how research can receive too little support over an extended period of time. Support will be too little because the funding decision is based on outdated information. For example, suppose that in 1980 actual expenditures are $100 million and optimal expenditures are $110 million. In 1981 the research agency will base funding decisions on the 1980 parameter values, calculate optimal expenditures to be $110 million and set actual expenditures to that level. However, shifts in research efficiency could have occurred so that the optimal 1981 expenditures (based on 1981 parameter values) are $120 million. Hence the 1981 actual expenditures will be less than the optimal expenditure. If shifts in research efficiency or demand for output continually occur, then actual expenditures will never catch up to optimal expenditures. If the response time is longer than one year, then the underfunding problem will be exacerbated. Recalling the discussion following theorem 1, this underfunding will be associated with high marginal returns to research, as are found in the empirical studies of agricultural research.

Two assumptions drive the result that agricultural research will be persistently underfunded. First, there are secular increases in the excess demand for research arising from increases in the derived demand for research or from increases in the efficiency of research (lower research costs). These are represented by increases in δ and ρ. Second, the research agency responds to these shifts only after a time lag. Theorem 3 makes this assumption by specifying that the optimizing calculation at time t occurs using parameter values from time $t-1$. These two assumptions are discussed in some detail.

Since the agricultural sector is far more complex than the model, considerable latitude will be used in interpreting the model and its assumptions. In particular, some of the factors influencing the excess demand for research have not been formally included in the model.

There are several reasons why the excess demand for research may shift over time. (1) The demand for agricultural output increases over time due to population increases and higher incomes. In the model these shifts are captured by increases in the demand parameter δ. When output demand increases, new techniques can be applied to a larger production base and hence their profitability increases. The demand for new techniques and the research needed to develop them increases. This result is similar to Evenson and Kislev's (1975) result on increasing scale. (2) The commercialization of agriculture leads to increases in the efficiency of research (Schultz, 1971). As agriculture becomes commercialized a higher proportion of food is allocated through markets. Market-oriented farmers have easier access to information about new inputs and new techniques, reducing the costs of disseminating the results of agricultural research. These lower costs are an increase in research efficiency. The model represents increases in research efficiency by increases in the research cost parameter ρ. (3) Farmers have increased their levels of education and human capital. Thus they are likely to have lower costs of learning new techniques, and to have the ability to implement these techniques more effectively. This leads to an increase in the efficiency of the research (and extension) producing these techniques. As above, the model captures the higher efficiency by increases in ρ. (4) Spillover from nonagricultural research and innovation increases the effectiveness of agricultural research and eases dissemination of the results. An example is the effect of innovation in the computer and information processing industry. Farmers with personal computers now have direct access to many price forecasting and farm management programs developed at research institutions (see Owen, 1982; Nott and Peters, 1984). This is an example in which ρ increases.

The second driving assumption is that there is a time lag between shifts in the excess demand for research and increases in appropriations. That such a lag exists is commonly accepted; indeed, it has been argued that one of the roles of economic research is to reduce this lag (Schultz, 1971). However, this statement implies that one of the roles of this paper should be to examine this lag more thoroughly.

There are many possible situations that could cause a lag in the response of appropriations to changes in the excess demand for research. (1) Indivisibilities in research projects may cause difficulty. An administrator desiring to expand program size can increase funding for existing projects and/or fund new projects. It may sometimes appear desirable on the margin to fund new projects, but indivisibilities or fixed costs make overall returns too small to justify the project. Thus actual funding will appear to lag behind desired funding. (2) Increases in research efficiency may not be discernible for many years. For example, corn hybridization research is one of the most monumental success stories in agricultural research, with an estimated rate of return in excess of 700% (Griliches, 1958). Yet this product took 30 years to perfect, and it took almost four decades from the start of this project to the time when the rate of return was calculated. Administrators cannot be expected to accurately estimate research efficiency when the final(?) results will not be in until forty years later. As another example, consider the recent advances in genetic engineering. These advances surely have increased the efficiency of some types of agricultural research. Yet it is unclear which projects are now worth undertaking, how efficient these projects are, and how much money should be devoted to these projects. An implication of this paper is that studies conducted 40 years from now will find rates of return indicating underfunding of these projects. [Recently a literature has evolved on ex ante evaluation of agricultural research projects (Binswanger and Ryan, 1977; Grieg, 1981; Shumway, 1981; Anderson and Parton, 1983) . Much of this literature follows benefit–cost methods of project evaluation (Harberger, 1972; Tolley and Townsend, 1985).] (3) An administrator reading this paper and believing this implication may still choose not to increase funding to the optimal level (and hence insure the accuracy of the implication). The reason for this behavior is that private incentives may not be compatible with the minimization of production costs. The administrator may face a private reward system that strongly penalizes mistakes caused by large reallocations of funds, while only mildly penalizing mistakes caused by limited reallocation of funds. The result is that research funding increases incrementally, and only after a delay — or perhaps never — reaches the desired level (Fishel (1971) suggests that incrementalism may be a second-best solution to the resource allocation problem for national research agencies; see also Tichenor and Ruttan, 1971). (4) Government officials responsible for appropriations for the funding agency may attempt to maximize benefits to their constituency, or have other incentives conflicting with the objective of minimizing production costs. (For a discussion of this problem in the U.S. Congress see Wade, 1973a,b; Phillips and Dalrymple, 1981). However, if research is underfunded then the misallocation of resources imposes costs on government, consumers, and producers (White and Havlicek, 1982). It is likely that these costs will rise over time (Holbrook, 1972; White and Havlicek, 1982), changing the government incentive structure. The price to government officials of underfunding the research agency will rise, and hence more funds will be allocated for research. Funding will move towards the optimal level, but only after a time lag.

Conclusions

This paper has developed a model explaining the low levels of public agricultural research funds that persist over time, across different types of research, and across countries. The driving assumptions are (1) that the excess demand for research increases over time, and (2) that the funding agency responds slowly to the change in the excess demand for research. Shifts in excess demand imply that the optimal level of funding increases over time. The slow response means that actual funding will lag behind optimal funding. That is, at any time there will be worthwhile projects that are not funded. The scarcity of funds implies that on average only those projects with extremely high rates of return are funded.

The paper relates the driving assumptions to descriptions of the research and research funding processes. The assumption that the excess demand for research increases over time will be valid if the demand for agricultural output increases over time, if farmers accumulate human capital, if the agricultural sector becomes more commercialized, or if research efficiency increases. The assumption that response is slow will be valid if there are indivisibilities in projects, if there are inadequate data on current and future research efficiency, or if the agency administrators and their superiors (e.g. the U.S. Congress) have conflicting goals and incentive structures.

Further work is needed to completely understand the response of research funding agencies to changes in the optimal level of funding. Three directions need to be investigated. (1) A more formally dynamic model of lagged adjustment can shed light on agency response to changing economic conditions. A general equilibrium approach would enhance the model's application to countries in which agriculture is the dominant sector in the economy. (2) The effect of political power on research appropriations by legislative bodies such as the U.S. Congress needs to be thoroughly discussed and if possible quantified. (3) The incentive structures facing researchers and administrators needs to be more thoroughly examined. Derivations of incentive-compatible reward structures are of great importance to developing countries that are starting up agricultural research programs as well as to developed countries that are in the process of redesigning their research institutions.

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Appendix

Theorem 1: Assume that $Cqa^2 < Cqq(Rac + Caa)$. Then under the model specification $\partial R/\partial\delta > 0$ and $\mathrm{d}R^*/\mathrm{d}\rho > 0$.
Proof: The equilibrium conditions are (3), (5) and (7). Totally differentiating the system yields $AX = B$, where

$$A = \begin{bmatrix} 1 & -Cqq & -Cqa \\ -Dp & n & 0 \\ 0 & Caq & Raa+Caa \end{bmatrix}, X = \begin{bmatrix} \mathrm{d}P \\ \mathrm{d}q \\ \mathrm{d}a \end{bmatrix} \text{ and } B = \begin{bmatrix} 0 \\ D\delta \mathrm{d}\delta \\ -Ra\rho \mathrm{d}\rho \end{bmatrix}$$

A direct calculation shows

$$A^{-1} = \begin{bmatrix} Z + CqqDp(Rac+Caa) - Cqa^2Dp & -Cqa^2 + Cqq(Raa+Caa) & (CqaZ - Cqa^3Dp)/(Raa+Caa) + DpCqqCqa \\ Dp(Raa+Caa) & Raa+Caa & DpCqa \\ -DpCaq & -Caq & Z/(Raa+Caa) - Cqa^2Dp/(Raa+Caa) \end{bmatrix}$$

where $Z = n(Raa + Caa) - CqqDp(Raa + Caa) + DpCqa^2$. Under the assumption that $Cqa^2 < Cqq(Raa + Caa)$ we have $Z > 0$. Thus

$$\partial a/\partial\delta = \mathrm{d}a/\mathrm{d}\delta \Big|_{\mathrm{d}\rho=0} = -CaqD\delta > 0.$$

$$\partial a/\partial\rho = \mathrm{d}a/\mathrm{d}\rho \Big|_{d\delta=0} = (-Caq + (Z - Cqa^2 D\rho)/(Raa + Caa))(-Ra\rho) > 0.$$

Hence $\mathrm{d}R(a,\rho)/\mathrm{d}\delta = Ra\partial a/\partial\delta > 0$. Note that

$$\lim_{n\to\infty} \partial a/\partial\rho = +\infty.$$

Thus $\mathrm{d}R(a,\rho)/\mathrm{d}\rho = Ra\partial a/\partial\delta + R\rho > 0$ for large n. Q.E.D.
Note that similar calculations give the sign conditions $\partial P/\partial\delta > 0$, $\partial q/\partial\delta > 0$, $\partial P/\partial\rho < 0$ and $\partial q/\partial\rho > 0$, as discussed in the text.