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EXTERNALITY, EFFICIENCY, AND EQUITY RELATED TO AGRICULTURAL RESEARCH EXPENDITURES

Fred C. White*

Introduction

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

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

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

*Professor, Department of Agricultural Economics, University of Georgia, Athens, Georgia.

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

Externalities Defined

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

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

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

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

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

Externality Impacts on Efficiency

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

An Efficient Aggregate Level of Expenditures

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

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

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

where

- Z is aggregate net benefits from production,
- P is price of output,
- W_a and W_b are costs per unit of research in states A and B, respectively, and
- a and b are research activity levels in states A and B, respectively.

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

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

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

The level of research activity that maximizes aggregate net benefits is that level at which the value of marginal product is equal to the per unit cost of research activity.

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

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

Efficient Allocation Among Research Areas

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

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

where

U^A is aggregate production affected by state A's research activities,

P_i is the price of the ith commodity,

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

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

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

B^0 is budget constraint for state A,

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

λ is the Lagrange multiplier.

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

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

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

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

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

The second alternative involves finding the efficient allocation of research expenditures when only internal benefits are considered. This alternative, which is characteristic of a state operating in its own best interest, involves internal benefits generated from local expenditures. From the first-order conditions when spillovers to other states are ignored

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

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

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

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

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

Expenditure Allocation With Risk

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

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

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

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

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

where

V^A is total variance of research benefits,

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

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

b is the level of research activities in state B.

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

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

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

Corrective Actions for Externalities

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

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

Voluntary Action Among States

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

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

Federal Government Action

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

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

Measurement of Externalities

In order to quantify the externalities associated with agricultural research, it must be assumed that research is a productive activity and that it is possible to accurately measure differences in this activity among states. The real value of agricultural research expenditures has widely been used for this purpose, but it is recognized that other measures which might include scientists' years conceivably could be used in identifying differences in research activity.

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

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

where

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

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

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

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

Conclusions

The allocational efficiency implications of externalities related to agricultural research have been examined conceptually in this paper. A major obstacle to efficient allocation of agricultural research activities in the past has been a lack of information on externalities associated with these activities. However, there is increasing evidence that research interest is being focused on empirically estimating the magnitude of spillover benefits from agricultural research. Even though available information is still incomplete, it is useful to consider what the efficient solution would be if the necessary information was available. The issues raised in this paper may be useful both to those who are applying quantitative techniques to the area of research evaluation at the sub-national level and to those who are studying public policies and institutions providing agricultural research activities.

The economic efficiency concepts developed in this paper are not to be considered the sole basis on which to determine the optimum level of research activities. Instead, these allocational efficiency concepts may be used to evaluate the consequences of selected allocation decisions or used in conjunction with other decision-making criteria. While economists tranditionally place major emphasis on the efficient allocation of resources, it is recognized that other criteria such as equitable income distribution are also important. Changes in the allocation of agricultural research activities in order to correct for externalities may have significant distributional effects.

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

Footnotes

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

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

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

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

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

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

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

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