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INTERREGIONAL SPILLOVER OF AGRICULTURAL RESEARCH RESULTS AND INTERGOVERNMENTAL FINANCE: SOME PRELIMINARY RESULTS

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Introduction

Agricultural research, as with many other governmental services, can be performed efficiently at the state level but produces benefits that accrue to a broader area than just the originating state or region. Results from basic research, for example, would be unrestricted by geographic boundaries. Even applied research which is designed to solve specific problems encountered in a particular state may result in spillovers--geographically external benefits--to other areas. For example, some research results can readily be applied over wide geographic areas while other results need only additional adaptive research before they are suitable for other areas.

The idea that the benefits of agricultural research are not realized solely by the state or region providing the research expenditures is not a new one. Several researchers have analyzed the interregional diffusion of a particular technology (Peterson and Hayami, 1977, pp. 524-526). In the study of hybrid corn diffusion, Griliches (1957) found that differences among regions in adoption rates were dependent on such factors as the size and density of commodity production and profitability of the new technology. Despite the widespread concern over the diffusion of a particular technology, the external benefits of agricultural research have not received much attention from economists working in the general area of research evaluation and planning.

Attempts at measuring the contribution of agricultural research to agricultural production have often utilized a production function for a commodity or agricultural sector as a whole in such a manner that research was included as a separate variable (Peterson and Hayami, 1977, pp. 520-521). The majority of studies which have included research as a separate variable in a production function have been aimed at the national level rather than the regional or state levels. Griliches' (1964) work was one of the first publications in the area and Evenson's (1967) work was really important because it revealed the nature of the lag between the research input and increased output. The production function approach provides an estimate of the marginal product of agricultural research which is particularly useful in guiding decisions about allocation of resources to agricultural research.

Studies directed at the state or regional level confront a major problem not encountered in a national analysis: interregional spillovers of the benefits from agricultural research results. This problem has been termed pervasiveness, indicating the tendency for research results generated in one region to be incorporated into farm production functions in other regions (Evenson, 1971, p. 173). Latimer and Paarlberg (1965) and Evenson (1971) recognized the pervasiveness problem. Latimer and Paarlberg were unable to find a statistically significant relationship between research expenditures within the state and agricultural output. They attributed these findings to the pervasive nature of agricultural research results (Latimer and Paarlberg, p. 239). Evenson included a variable which measured the intensity of commodity research in an attempt to control for the pervasiveness of research (1971, p. 177). If research results were completely pervasive, Evenson argued, this variable would dominate the state research variable. The variable was statistically significant indicating that the interregional transfer of agricultural research results should be taken into account in cross-sectional analyses.

The existence of spillover benefits has a bearing on the allocation of research funds both within and between states. One important problem is to determine the appropriate balance between federal and state government in financing agricultural research. More specifically, what portion of the research expenditures should be financed by the federal government? The federal government initially served as a catalyst

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in developing the institutional framework to conduct agricultural research. The Morrill Land Grant College Act of 1862 and the Hatch Agricultural Experiment Station Act of 1887 reflect the emergence of a dual federal-state approach to agricultural research (Peterson and Fitzharris, 1977, pp. 72-73). Under these acts, each state received funds for a college of agricultural and mechanical arts and for an agricultural experiment station. This institutional framework is still a dominant force in agricultural research. Federal funds are allocated by a formula which is based largely on a state's rural and farm population (Peterson and Hayami, 1977, p. 522). Assuming that this system of finance was appropriate when it was first devised, is it still equitable after almost a century?

This paper deals with the effects of spillovers of agricultural research benefits on the financing of research by federal and state governments. It considers conceptual problems of financing government services which produce spillovers and proposes a model to align a region's investment in agricultural research with social benefits by compensating for spillovers with funds from the federal government. Interregional spillovers of the benefits from agricultural research results are empirically measured in order to determine the appropriate balance between federal and state funding of agricultural research.

Conceptual Framework for Financing Externalities

The purpose of this section is to investigate the nature of the divergence between regional and social benefits from agricultural research and the ways in which the federal government can make them coincide. Particular attention will be focused on the rationale for intergovernmental grants from the federal government to finance agricultural research.

A production externality occurs whenever results from agricultural research investments in one region affect agricultural production in other regions.1/ This phenomenon of interdependence in production can be analyzed through the basic model of joint production. Consider the case in which a production possibility schedule for agricultural output in region i is assumed to be related to the quantity of conventional inputs employed in region i, as well as research expenditures within region i and in other regions. The problem is further complicated by the fact that research expenditures over several years may affect agricultural output. The appropriate model of joint production is given by:

$$(1) \quad F(Q_{1t},---,Q_{nt}, X_{11t},---,X_{mnt},R_{1t},---R_{1t-w}, ---R_{nt-W}) = 0$$

where

Q_{it} is the agricultural output in region i and time period t,

X_{ijt} is the jth conventional input in region i and time period t,

$R_{i(t-w)}$ is agricultural research expenditures in region i and time period t-w.

i=1,2,---n is the number of regions,

j=1,2,---m is the number of conventional inputs,

t=1,2,---T is the number of time periods and,

w=0,1,2,---W is the number of lagged time periods over which agricultural research affects the output of the current time period.

This implicit function, which defines the set of inputs and outputs that may be feasibly attained is subject to the following conditions related to any regions i and k.

$$\frac{\partial Q_{it}}{\partial R_{k(t-w)}} \geq 0 \text{ for } w=0,1,2,---W$$

$$\frac{\partial Q_{it}}{\partial X_{kjt}} = 0 \text{ for } i \neq k$$

These conditions state that research in one region may affect output in other regions but conventional input usage in one region has no effect on output in any other region.

The existence of externalities complicates the dual problems of optimal provision and financing of agricultural research. First, consider society's problem in finding the optimum amount of research expenditures subject to the production constraint. One such procedure is to increase research expenditures up to the point where its internal rate of return is just equal to returns from alternative social investments (r_i).

$$(2) \quad \sum_{w=0}^{W} \frac{P_{it} MP_{i(t-w)}}{(1+r_i)^w} -1 = 0$$

where

P_{it} is the price of the output in region i and time period t,

$MP_{i(t-w)}$ is the marginal product of research in region i and time period t-w, and

r_i is the rate of return in region i for the best alternative social investments.

This condition can also be interpreted as selecting the level of research expenditures whose marginal benefits discounted at the social rate of return is just equal to its marginal cost. Thus, on the margin each dollar of expenditures will generate benefits equal to one dollar in present value.

The partial derivative of the production function with respect to research in the ith region is:

$$(3) \quad MP_{i(t-w)} = \frac{\partial Q_{it}}{\partial Ri(t-w)} + \sum_{k \neq i} \frac{\partial Q_{kt}}{\partial R_{i(t-w)}} \quad \text{for} \quad w=0,1,2,---,W$$

This expression indicates that the marginal benefits of region i can be separated into two components, benefits accruing to region i and benefits accruing to other regions. In selecting the appropriate level of research expenditures, policy makers in region i will stress those benefits which accrue to the region and ignore those spilling over to other regions. With positive net spillovers, the level of research expenditures is likely to be too small relative to the interests of the country as a whole if the activity is financed at the regional level. This situation is depicted in Figure 1 by the region's selection of R_1 as the appropriate level of research expenditures with the choice based on equating marginal efficiency of research investment from the regional perspective (mer_i) with the social rate of return (r). This decision-making process ignores the marginal efficiency of research investment from the national perspective (mer_N), which indicates that the socially optimum level of research expenditures is R_2. The externality problem raises the issues of society's optimal financing of agricultural research.

If the level of expenditures in each region was based on benefits to the nation as a whole rather than the benefits to the region, the potential inefficiency would be resolved. In those cases in which only a small number of decisionmaking units are involved, voluntary action among the interested parties could be used in such a manner that all benefits are considered (Oates, pp. 67-68). However, attempting to coordinate these activities involves costs which increase rapidly as larger numbers of parties are involved. Externalities from agricultural research affect a large number of decisionmaking units, and therefore the costs and the difficulties of effective coordinated action is expected to be quite large. One feasible solution, short of transfering the research activity to the federal government, is for the federal government to grant funds to the state to induce it to raise the level of agricultural research.

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 regional expenditures toward optimum levels by financing the cost of external benefits or internalizing the externalities. This procedure can best be understood by referring to Figure 1. The socially optimum level of research expenditures is R_2 found at the intersection of r, the social rate of return, and mer_N, the marginal efficiency of research investment from the national perspective. Since the region's decision on research funding is based on mer_i, the matching grant program from the federal government should reduce the region's effective cost to r'. The region will therefore choose R_2 as the appropriate level of research expenditures by equating marginal regional benefits (mer_i) with marginal regional costs (r'). The matching formula in this case will be $(r - r')/r'$ as the appropriate balance between federal and regional funding of agricultural research.

The development of an appropriate matching grant program requires identification and quantification of regional benefits and spillovers from agricultural research. The traditional prescription to compensate for externalities, as proposed by A. C. Pigou (1932), is to provide a unit subsidy equal to the value at the margin of the spillovers. This concept is used in the present analysis to measure regional benefits and spillovers. Benefits from agricultural research expenditures in a given region from the regional point of view are measured by the contribution of the expenditures to output within the region:

$$(4) \quad B_{it} = P_{it} \left[\sum_{w=0}^{W} \frac{\partial Q_{it}}{\partial R_{i(t-w)}} R_{i(t-w)} \right]$$

where

B_{it} is the value of the regional benefit in time period t from agricultural research expenditures in region i during the w=0, 1,2,---,W previous time periods.

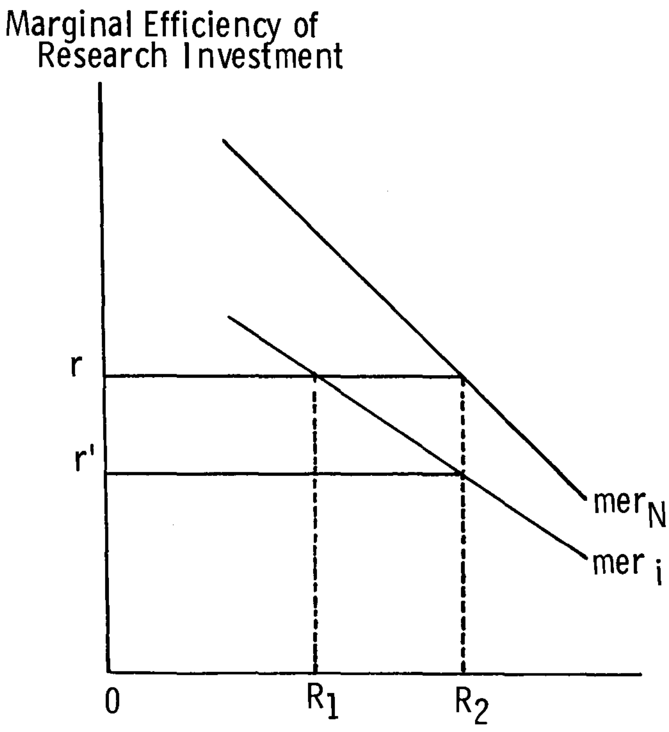
Valuing benefits by this criterion is equivalent to paying resouces according to their marginal productivities. Similarly, spillovers of agricultural research conducted in region i are measured by the contribution of the expenditures to output in all other regions:

$$(5)\quad S_{it} = \sum_{k\neq i} P_{kt} \left[\sum_{w=0}^{W} \frac{\partial Q_{kt}}{\partial R_{i(t-w)}} \cdot R_{i(t-w)} \right]$$

where

S_{it} is the value of spillover benefits in time period t from agricultural research expenditures in region i during the w=0,1,2,--- W previous time periods.

Figure 1. Adjustment for External Benefits



Total benefits to the nation in time period t resulting from expenditures in region i are the sum of the benefits to the originating region, B_{it} and spillovers, S_{it}. The relative importance of spillovers to regional benefits in time period t is measured by:

$$(6)\quad M_{it} = \frac{S_{it}}{B_{it}}$$

where

M_{it} is the ratio of spillovers to regional benefits in time period t.

In developing a federal grants program, M_{it} could be used as a guide in determining the federal government's share of research expenditures (Musgrave and Musgrave, 1976, p. 630).

The impact of federal grants on the level of research expenditures is dependent on the magnitude of the marginal revenue from grants. However, it is possible to draw some general conclusions relating to the suitability of federal grants for achieving particular objectives. First, a matching grant program for agricultural research would tend to increase the level of these expenditures by reducing the net price of agricultural research relative to other public and private goods. Secondly, the program would help correct for spillovers so that regional benefits would more closely coincide with social benefits.

The Model

In this study a production function which includes variables to reflect conventional inputs as well as agricultural research is estimated and is the basis for measuring the contribution of research to agricultural production. Various outputs are aggregated into a single variable by using relative price weights. Input variables are similarly aggregated and will thus abstract from quality differences that are not reflected in input prices. While this estimation procedure controls for the use of other inputs that are expected to influence agricultural output, we are particularly interested in the effect of agricultural research on productivity. The expected relationship between agricultural research and agricultural output is discussed in the following paragraphs.

Ideally, we would like to capture the spillovers of research results from region i to region k for every i and k. However, accounting for such a large number of interregional flows would be very difficult in a single regression equation. Furthermore, for purposes of this study it is only necessary to measure the magnitude of spillovers in aggregate and not to identify the originating region in each case. Thus, the model will contain separate variables for research expenditures inside the region and research expenditures outside the region. The spillovers in aggregate (or spillins) into the ith region in time period t are:

$$(7) \qquad SI_{it} = \sum_{k \neq i} P_{it} \left[\sum_{w=0}^{W} \frac{\partial Q_{it}}{\partial R_{k(t-w)}} \cdot R_{k(t-w)} \right]$$

where

SI_{it} is the value of the spillover benefits into region i in time period t from agricultural research expenditures in the other (n-1) regions during the w=0,1,2, ---,W previous time periods.

The time path of output response to increased expenditures on research is particularly important in estimating the benefits from research. If the output response is not forthcoming in the same year the investment is made, then the estimated marginal product overstates the marginal returns from research investment. Evenson was perhaps the first to identify the nature of the lag between the research input and increased output. He found, that in response to increased expenditures on research, agricultural output first increased and then decreased, with the average length of lag between six and seven years. At the regional level this lagged relationship is assumed to exist for research expenditures both within the region and outside the region.

Extension investment within the region also affects agricultural output. However, measuring the influence of extension on agricultural productivity separate from research has been difficult. If extension's role is distinct from that of research, then a separate extension variable should be used in the production function. However, if extension's role can be viewed as improving labor quality, its effect on productivity can be considered similar to that of research. Consequently, it would be difficult to distinguish between the contribution of research and extension (Evenson, 1967, p. 1421). The latter case is assumed to be the appropriate situation in the present study. Therefore, research and extension expenditures within the region are combined into one variable. Extension is assumed to have no spillover effect to other regions.

The model used as the basis for empirical analysis is:

$$(8) \qquad Q_{it} = \beta_0 \prod_{j=1}^{m} X_{ijt}^{\beta j} \prod_{w=0}^{W} RI_{i(t-w)}^{\beta_{m+w}} \prod_{v=0}^{V} RO_{i(t-v)}^{\beta_{m+W+v}}$$

where

Q_{it} is the value of agricultural output per acre in region i and time period t,

X_{ijt} is the per acre value of the jth conventional input in region i and time period t,

$RI_{i(t-w)}$ is the research and extension expenditures per state inside region i for time period (t-w),

$RO_{i(t-v)}$ is the research expenditure per state outside region i for time period (t-v),

β's are regression coefficients,

i=1,2,---,n is the number of regions,

j=1,2,---,m is the number of conventional inputs,

t=1,2,---,T is the number of time periods,

w=0,1,2,---,W is the number of lagged time periods over which agricultural research and extension expenditures within a region affect agricultural output in region i during time period t, and,

v=0,1,2,---,V is the number of lagged time periods over which agricultural research expenditures outside of region i affect agricultural output in region i during time period t.

A production function such as the one presented above provides several sets of interrelated relationships that are important for economic decisions on resource use. Considering the unique aspects of the present analysis, attention will be focused on factor-product transformation ratios for research and extension inside the region and research outside the region.

Statistical Model and Data

The unit of analysis is an average state for each of the 10 agricultural production regions in the United States.2/ Estimates of the contribution of agricultural research to agricultural output are obtained from a production function which was estimated using data for the period 1949-1972. Data on research expenditures covered the period 1929-1972 to account for lagged effects of the research variables.

The statistical model is a cross-sectionally correlated and time-wise autoregressive double logarithmic production function with four conventional inputs and the research expenditures inside the region and outside of the region included as second order polynomial lags. The statistical production function is:

$$(9) \qquad \ln Q_{it} = \ln \beta_0 + \beta_1 \ln X_{i1t} + \beta_2 \ln X_{i2t} + \beta_3 \ln X_{13t} + \beta_4 \ln X_{i4t} + \beta_5 \ln RI_{it} + \beta_6 \ln RO_{it} + \varepsilon_{it}$$

where

$\ln Q_{it}$ is the natural logarithm of the value of agricultural output per acre in region i and time period t,

$\ln X_{i1t}$ is the natural logarithm of the per acre value of hired labor in region i and time period t,

$\ln X_{i2t}$ is the natural logarithm of the per acre value of feed and livestock in region i and time period t,

$\ln X_{i3t}$ is the natural logarithm of the per acre value of seed, fertilizer, lime and miscellaneous expenses in region i and time period t,

$\ln X_{i4t}$ is the natural logarithm of the per acre value of capital and depreciation in region i and time period t,

$\ln RI_{it}$ is the research and extension expenditure per state inside production region i pertaining to time period t measured as a second order polynomial in logarithms covering a 11-year lag and having both endpoints constrained to zero,

$\ln RO_{it}$ is the research expenditure per state outside region i pertaining to time period t measured as a second order polynomial in logarithms covering a 11-year lag and having both end points constrained to zero,

$\beta_0, \beta_1, \text{---}\beta_6$ are parameters and,

ε_{it} is the disturbance term associated with t^{th} observation in region i.

ε is assumed to be log normally distributed with the following behavioral attributes:

$$E(\varepsilon_{it}^2) = \sigma_{ii} \qquad \text{(heteroskedasticity)}$$

$$E(\varepsilon_{it}\ \varepsilon_{kt}) = \sigma_{ik} \qquad \text{(mutual correlation)}$$

$$\varepsilon_{it} = \rho_i\ \varepsilon_{i(t-1)} + U_{it} \qquad \text{(autoregression)}$$

U_{it} is assumed to be log normally distributed and

$$E(\varepsilon_{i(t-1)}\ U_{kt}) = 0$$

$$E(U_{it}\ U_{kt}) = \phi_{ik} \qquad \text{(variance-covariance matrix after adjustment for serial correlation)}$$

$$E(U_{it}\ U_{ks}) = 0 \qquad (t \neq s),$$

for i,k=1,2,---,n and t=1,2,---,T.

The parameters of (9) were estimated using a generalized least squares procedure which estimates a serial correlation coefficient for each region and adjustments for serial correlation are made in each region using the estimated regional serial correlation coefficient. After adjustment for serial correlation, the variance-covariance matrix for the agricultural production regions is estimated and the coefficients of the model are estimated relative to adjustments for heterogeneous variances and non-zero covariances among the regions.

Agricultural input and output data were obtained from Farm Income Estimates, 1949-1972 (U.S. Department of Agriculture). Agricultural output was the sum of farmer cash marketing, government payments to farmers, value of home consumption of farmers, and net farm inventory change. Four conventional input-expenditure categories were used: (1) hired labor, (2) feed and livestock, (3) seed, fertilizer, lime, and miscellaneous expenses, and (4) capital and depreciation. Agricultural output and all expenditures were recorded in million 1972 dollars.3/

Research and extension expenditures included only production-oriented expenditures. Data sources for these expenditures include Budget of the United States Government; Combined Statement of Receipts, Expenditures and Balances of the United States Government (U.S. Department of Treasury); Funds for Research at State Agricultural Experiment Stations and Other State Institutions (U.S. Department of Agriculture, Cooperative State Research Service); and Annual Report of Cooperative Extension Work in Agriculture (U.S. Department of Agriculture, Federal Extension Service). For a more detailed description of data sources see Cline (1975). Research and extension expenditures were also recorded in million 1972 dollars, with the personnel component of these expenditures deflated with an index of average salaries of college and university teachers (AAUP Bulletin) and the remaining expenditures deflated by the implicit price deflator for government purchases of goods and services.

Results

Empirical Production Function

The statistical results based on the data for the 10 production regions of the United States for the period 1949-1972 are presented in this section. Estimated regression coefficients and t-values are shown in Table 1. The sign of each coefficient on conventional inputs and education are consistent with *a priori* knowledge. Each of these coefficients is also different

Table 1: Empirical Production Function Which Accounts for Interregional Spillovers of Agricultural Research Results.

Variable	Coefficient	Standard Error
Hired Labor	0.153122**	0.018093
Feed and Livestock	0.167828**	0.021168
Seed and Fertilizer	0.218450**	0.026108
Capital and Depreciation	0.467536**	0.023348
Year	Research and Extension Inside the Region	Research Outside the Region
t	0.000000	0.000000
t-1	0.003520	0.000000
t-2	0.006336	0.000000
t-3	0.008448	0.006130
t-4	0.009856	0.011034
t-5	0.010560	0.014712
t-6	0.010560	0.017164
t-7	0.009856	0.018390
t-8	0.008448	0.018390
t-9	0.006336	0.017164
t-10	0.003520	0.014712
t-11	0.000000	0.011034
t-12	0.000000	0.006130
t-13	0.000000	0.000000
Sum of Research and Extension Coefficients	0.077440**	0.134860**

**Statistically significant at the 0.01 level of significance.

from zero at the 0.01 level of significance. In particular, the elasticity of production is smallest for labor and highest for capital. It is also interesting to note that the sum of the coefficients on conventional inputs is approximately one, indicating constant returns to scale without the influence of research.

As indicated in equation (9) the model to be estimated in this study contained lags on research and extension expenditures within the region and research expenditures outside the region. In addition, research expenditures outside the region would probably not affect the regional output immediately, indicating a more complicated lagged structure associated with these expenditures. Second-degree polynomial expenditure lags4/ which were considered appropriate for this study were chosen from a large number of regression equations using different time lags with the final choice being on minimum mean square error. Research and extension expenditures within the region affected regional output for 11 years. Research expenditures outside the region had no effect on regional output for the first two years and then affected regional output for 11 years. Combining these two separate effects from the regional analysis indicates that research and extension expenditures affect agricultural output over a 13-year period. These results are consistent with aggregate studies by Evenson (1967) and Cline (1975) which found a 13-year lag. However, the present analysis sheds further light on the nature of the lag, indicating the importance of interregional flows of research results.

The effect of these expenditures on output in each year is also shown in Table 1. Research and extension expenditures inside the region have the greatest impact on regional output in the fifth and sixth years, while research outside the region has the greatest impact in the seventh and eighth years. The sum of the regression coefficients on research and extension expenditures inside the region is 0.0695 indicating that a 1% increase in research and extension expenditures increases output in the region by 0.0695% over its lifetime. These results are similar to estimates reported in previous studies.

Marginal Product and Rate of Return

The marginal product and rate of return for agricultural research and extension investment can be calculated from the regression results. The regression coefficients on the research and extension expenditure variables are elasticities. However, these elasticities can be converted to marginal products by the following equation:

$$(10)\quad TMPR_i = \sum_{w=0}^{W} MPR_{i(t-w)} = \sum_{w=0}^{W} \beta_{(t-w)} (\bar{Q}_i / \overline{RI}_i)$$

where

$TMPR_i$ is the marginal product of research and extension expenditures for region i aggregated over the lifetime of the investment,

$MPR_{i(t-w)}$ is the marginal product of research and extension expenditures in i and year (t-w),

$\bar{Q}_i$ is the mean level of agricultural output per state in region i, and

$\overline{RI}_i$ is mean level of research and extension expenditures per state in region i; both means are based on the 24 year period 1949-1972.

The marginal products for research and extension expenditures for the 10 regions are presented in Table 2. These estimates reflect the contribution to regional output of research and extension.

Table 2. Regional Estimates of Benefits and Funding of Production-Oriented Agricultural Research and Extension: Averages for the 1949-72 Period Expressed in 1972 Dollars.

Region	Marginal Product	Regional Rate of Return	Average Annual Regional Benefits	Average Annual Spillovers	Ratio of Spillovers to Regional Benefits	Ratio of Federal-State Expenditures
	(Dollars)	(Percent)	---(Million	Dollars)---		
Northeast	7.28	43.5	512.86	673.75	1.31	0.97
Lake States	4.99	32.5	241.17	658.74	2.73	1.10
Corn Belt	8.20	47.2	632.20	1,288.79	2.04	1.25
Northern Plains	12.27	61.7	536.39	753.59	1.40	1.63
Appalachian	10.30	55.1	610.85	726.62	1.19	1.60
Southeast	5.92	37.2	367.42	513.61	1.40	1.37
Delta	4.77	31.3	220.80	548.51	2.48	1.80
Southern Plains	4.78	31.4	215.51	604.48	2.80	2.10
Mountain	7.98	46.4	474.88	758.26	1.60	2.35
Pacific	5.13	33.3	370.22	698.33	1.89	0.90
Aggregate	6.51	40.0	4,182.29	7,224.27	1.73	1.38

The Northern Plains and Appalachian Regions have the highest marginal productivity, reflecting relatively low levels of research and extension investments. In contrast, the Lake States, Southern Plains, and Delta Regions have the lowest marginal productivity. The "average" marginal product, which was estimated using national averages for agricultural output and research and extension expenditures, was $6.51 indicating the total returns from $1 invested.

Since the returns are not forthcoming immediately, it is important to determine the rate of return associated with research and extension investments. The regional rate of return (r_i) can be calculated as follows:

$$(11) \quad \sum_{w=0}^{W} MPR_{i(t-w)}/(1+r_i)^{w} - 1 = 0$$

This procedure explicitly accounts for the lag structure. The regional rate of return for research and extension investments are reported in Table 2. The average regional rate of return is 40%, ranging from 31 to 62%. There is a direct relationship between marginal products and rate of return on investment, since the same lag structure is assumed to exist in every region.

The rates of return estimated in this study are in serious conflict with estimates made in earlier studies. Evenson (1971) reported returns that ranged from 30 to 180% for the same 10 regions. His average rate of return and average marginal product for research and extension investments were more than double the estimates reported in the present study. This discrepancy can be explained by the fact that Evenson did not account for the interregional transfer of research results. Furthermore, the rates of return presented in Table 2 are regional rates of return and not social rates of return which include spillovers of research results.

Evaluation of the rates of return reported in Table 2 indicate that investments in agricultural research and extension yield a high rate of return (from 31 to 62%) for the originating region. It would appear that the returns from this type of investment would compare favorably with alternative public investments in the region even without considering spillovers to other regions.

Intergovernmental Finance

Regional benefits and spillovers are compared to develop a mechanism for reallocating costs between the federal government and the region on the basis of benefits realized within each region. Empirical estimates of regional benefits can be calculated as follows:

$$(12) \quad B_i = \sum_{w=0}^{W} \beta_{(t-w)} (\overline{Q}_i/\overline{RI}_i)(\overline{RI}_i) = TMPR_i \; (\overline{RI}_i)$$

where

B_i is regional benefits for region i,

$\beta_{(t-w)}$ is the regression coefficient of research and extension expenditures in year (t-w),

$\bar{Q}_i$ is mean level of agricultural output per state in region i,

$\overline{RI}_i$ is mean level of research and extension expenditures per state in region i, and

$TMPR_i$ is marginal product of research expenditures in region i.

This condition states that regional benefits are the product of (a) the level of research and extension expenditures and (b) its value marginal product. Calculating regional spillovers, which is slightly more complicated, begins with the calculation of spill-ins (SI) for each region.

$$(13) \quad SI_i = \sum_{v=0}^{V} \beta_{(t-v)} (\bar{Q}_i/\overline{RO}_i) \overline{RO}_i = TMPRO_i (\overline{RO}_i)$$

where

SI_i is spill-ins of agricultural research benefits in region i,

$\beta_{(t-v)}$ is a regression coefficient on the variable research expenditures outside the region in year (t-v),

$\bar{Q}_i$ is mean level of agricultural output per state in region i,

$\overline{RO}_i$ is mean level of research expenditures outside region i, and

$TMPRO_i$ is marginal product of research expenditures outside of region i.

These spill-ins in region i are allocated among neighboring regions in proportion to total research expenditures, which provides an estimate of spillovers from region i to region k. The process of calculating spill-ins in every region and allocating to the originating regions is repeated until all spill-ins have been accounted for.

$$(14) \quad S_i = \sum_{k \neq i} SI_k (R_i / \sum_{l \neq k} R_l)$$

where

S_i is the value of spillover benefits from agricultural research expenditures in region i,

R_i is the level of research expenditures in region i, and

R_l is the level of research expenditures in all regions that generate spillovers into region k.

Empirical estimates of regional benefits and spillovers as defined by equations (12) and (14), respectively, are shown in Table 2. 5/ These figures are annual averages for the 1949-1972 period reported in 1972 dollars. Regional benefits are highest in the Corn Belt. Four regions --the Corn Belt, Appalachian, Northern Plains, and Northeast--generated over $500 million annually in regional benefits. With regards to spillovers of agricultural research benefits, all 10 regions generated more then $500 million of spillovers annually. The Corn Belt annually generated over $1.25 billion of spillovers to lead all regions in the amount of spillovers.

The average ratio of spillovers to regional benefits is 1.73 (Table 2). The Northeast and the Appalachian Regions have the lowest ratio of spillovers to regional benefits. Four regions have spillover-to-regional benefit ratios higher than two to one: Lake States, Corn Belt, Delta and Southern Plains. These differences can be explained by two factors: (1) the ratio of agricultural output to research and extension expenditures and (2) the ratio of extension to research expenditures. Those regions with low levels of research and extension expenditures relative to agricultural output have high marginal products for research and extension expenditures. Extension is assumed to create only regional benefits and not spillovers; thus, those regions in which extension is relatively important would have lower ratios of spillovers to regional benefits.

The ratio of federal-to-state expenditures for agricultural research and extension, which are presented in Table 2, can be compared with the ratio of spillovers to regional benefits to determine whether the federal government actually financed the spillovers. These results indicate that the federal government financed all of the spillovers in only three regions, Northern Plains, Appalachian, and Mountain Regions. In aggregate, the ratio of federal-to-state expenditures is only 1.38 compared to 1.73 for the ratio of spillovers to regional benefits. Thus the federal government's contribution to production oriented agricultural research and extension expenditures would have to be increased 25% to align regional funding with regional benefits, on the average. However, several regions would require a greater increase in federal expenditures to yield an equitable distribution across all regions.

Implications

The ratio of spillovers to benefits for any region is not a constant but depends on the marginal productivity of research inside the region, as well as outside the region. A given unit subsidy would not ensure that the federal government would finance its appropriate share of agricultural research as determined by the relative importance of spillovers. Maintaining the proper balance between federal and state government finance would require a variable matching formula, one in which the shares of the federal government and the state governments varied with the level of research expenditures.

Determination of the appropriate funding necessary to induce efficient behavior is a complex matter. While this study has shown that matching grants can provide a theoretical solution to the externalities problem, it is not the purpose of this study to propose a matching grant program for agricultural research. Instead, the intergovernmental grant program developed in this paper was presented as an analytical framework for evaluating the current system of federal support for agricultural research.

The limited scope of this analysis resulted in shortcomings that should be taken into consideration. First, the spillovers considered in this analysis were at the regional level rather than the state level. Benefits to the originating state would be less than regional benefits and conversely spillovers outside the state would be greater than spillovers outside the region. This study was focused at the regional level because previous research had indicated that it would be more likely to quantify systematic spillovers of agricultural research results among regions than among states. Results of this study demonstrate that interregional spillovers can be empirically measured. However, further research is needed.

Secondly, the production function estimated in this study can measure only average tendencies with respect to interregional spillovers. Thus, greater confidence can be placed on the aggregate estimates of regional benefits and spillovers than on the estimates for a particular region. Individual studies, region by region, would have to be undertaken in order to precisely measure the interregional flows of research benefits for a particular region. The authors have conducted such a study for the Southern Region, which includes four regions of the present study--Appalachian, Southeast, Delta, and Southern Plains. Results of that study indicated an internal rate of return of 20% for agricultural research and extension investment in the Southern Region. It is interesting to note that if the interregional spillovers had been ignored in formulating the model, the results would have incorrectly indicated a 72% rate of return on regional investment. These figures indicate the magnitude of the bias that results from failure to account for interregional spillovers of agricultural research results.

Conclusions

Interregional spillovers of agricultural research results create difficult problems related to the allocation and finance of research expenditures. As a result of these spillovers, regional benefits diverge from social benefits and therefore action by the federal government is needed to ensure that the level of research investment is optimum. Action by the federal government to deal with this type of problem has generally been in the form of intergovernmental grants which can be used to ensure that regional and social benefits coincide.

While the need for intergovernmental grants for agricultural research has been justified in this study primarily on the basis of interregional spillovers, the existence of spillovers is certainly not the only factor that should be taken into consideration in determining the federal government's support for agricultural research. Ideally, the returns from agricultural research investment will have to be compared with other investment alternatives. Thus interregional spillovers of agricultural research results is only one facet to be considered in determining the appropriate balance between federal and state governments in financing agricultural research. However, it is hoped that this study has contributed to the general understanding of agricultural research finance by identifying and quantifying interregional spillovers of agricultural research results.

Footnotes

1/For discussions of externalities see Buchanan and Stubblebine (1962), Davis and Whinston (1962), and Mishan (1971).

2/The 10 production regions correspond to a U.S. Department of Agriculture delineation as reported in such publications as Farm Real Estate Market Developments (U.S. Department of Agriculture).

3/Data source for price deflators was Agricultural Statustics (U.S. Department of Agriculture). Value of agricultural output was deflated with the index of prices received by farmers for all farm products. The labor input for agricultural hired labor was deflated by the index of prices paid for hired labor. Total expenditures for feed and livestock were deflated with the index of prices paid for feed and livestock, respectively. Total expenditures for seed, fertilizer, lime, and miscellaneous expenses were deflated with prices paid for seed, fertilizer, and all items in production, respectively. The capital and depreciation variable was the farm expenditures for repair and operation of capital items, and depreciation and other consumption of farm capital deflated by the index of prices paid for all items in production.

4/Previous research by Evenson (1967) and Cline (1975) indicated that a second-degree polynomial was most appropriate from both a theoretical and an empirical perspective.

5/One difference between the conceptual models of regional benefits and spillovers, equations (4) and (5), and their empirical counterparts equations (10) and (12) is that no price variable is explicitly considered in the latter two equations. The reason for this difference is that value rather than quantity is used as the dependent variable in the empirical estimation of the production function. Hence, the derivative of the production function with respect to research expenditures is value marginal product.

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