INTERREGIONAL TRANSFER OF AGRICULTURAL RESEARCH RESULTS: THE CASE OF THE NORTHEAST

Joseph Havlicek, Jr. and Fred C. White

ABSTRACT

The contribution of research to agricultural production is measured by estimating a production function which includes variables to reflect conventional inputs as well as agricultural research. Conventional inputs considered are hired labor, feed and livestock, seed and fertilizer, and capital and depreciation. Investment in agricultural research and extension within the region and investment in agricultural research in other production regions of the U.S. are included in the production function. Marginal products and internal rates of return are derived for the own region and outside-the-region investments in agricultural research.

The empirical results indicate that some agricultural production regions have a greater capacity for exporting agricultural research results while some have a greater capacity for importing agricultural research results from other production regions. Of the ten agricultural production regions of the U.S., the Northeast had the lowest marginal product per dollar invested in agricultural research during the 1977-81 period and the lowest internal rate of return to investment in agricultural research. For the same time period the average annual spillovers from the Northeast were approximately 3.3 times as large as the average annual regional benefit and the spillovers from the Northeast were about 2.3 times as large as the spill-ins into the Northeast region. The ratio of federal to state expenditures on agricultural research in the Northeast was 1.03 and compared to a ratio of spillover's to regional benefits of 3.3 suggests that the Northeast does not fare well in terms of federal support of agricultural research benefiting other regions of the U.S.

INTRODUCTION

Agricultural research, as with many other governmental services, can be efficiently performed at the state level but produces benefits that accrue to a broader area than just the originating state. Results from basic research, for example, are unrestricted by geographic boundaries. Even applied research which is designed to solve specific problems encountered in a particular state may result in spillovers 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 providing the research expenditures is not a new one. Several researchers have analyzed the interregional diffusion of a particular technology (see Peterson and Hayami, 1977, pp. 524-526). In the study of hybrid corn diffusion, Griliches (1957) found that differences among regions in adoption rates are 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 been largely neglected by economists working in the general area of research evaluation and planning.

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 governments 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 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, it is questionable whether after a century it is still equitable.

This paper deals with the effects of spillovers of agricultural research benefits among production regions of the U.S. and analyzes the pattern of spillovers relative to the pattern of federal funding of agricultural research in the various production regions. Conceptualization problems of financing government services which produce spillovers are considered and a model to align a region's investment in agricultural research with social benefits by compensating for spillovers with funds from the federal government is proposed. Interregional spillovers of the benefits from agricultural research results are empirically measured in order to determine the

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Joseph Havlicek, Jr. is Professor and Chairman of the Department of Agricultural and Resource Economics at the University of Maryland and Fred C. White is Professor of Agricultural Economics at the University of Georgia.

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appropriate balance between federal and state funding of agricultural research.

PRODUCTION EXTERNALITIES

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:

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

where

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

X_{ijt} is the j^{th} 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,

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 feasible set of inputs and outputs, is subject to the following conditions related to any regions i and k:

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

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

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 price of 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 from 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 generates benefits equal to one dollar in present value.

The partial derivative of the production function with respect to research in the i^{th} region is

$$(3)\quad MP_{i(t-w)} = \frac{\partial Q_{it}}{\partial R_{i(t-w)}} + \sum_{k\neq i} \frac{\partial Q_{kt}}{\partial R_{i(t-w)}}$$

$$\text{for } w = 0,1,2,\ldots W$$

This expression indicates that the marginal benefits of research in 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 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 issue of society's optimal financing of agricultural research. The traditional prescription to compensate for externalities, as proposed by A. C. Pigou (1932), is for the Federal government to provide a subsidy or grant. The development of an appropriate grant program requires identification and quantification of regional benefits and spillovers from agricultural research. From the regional perspective, the benefits from agricultural research expenditures are measured by the contribution of the expenditures to output within the region:

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

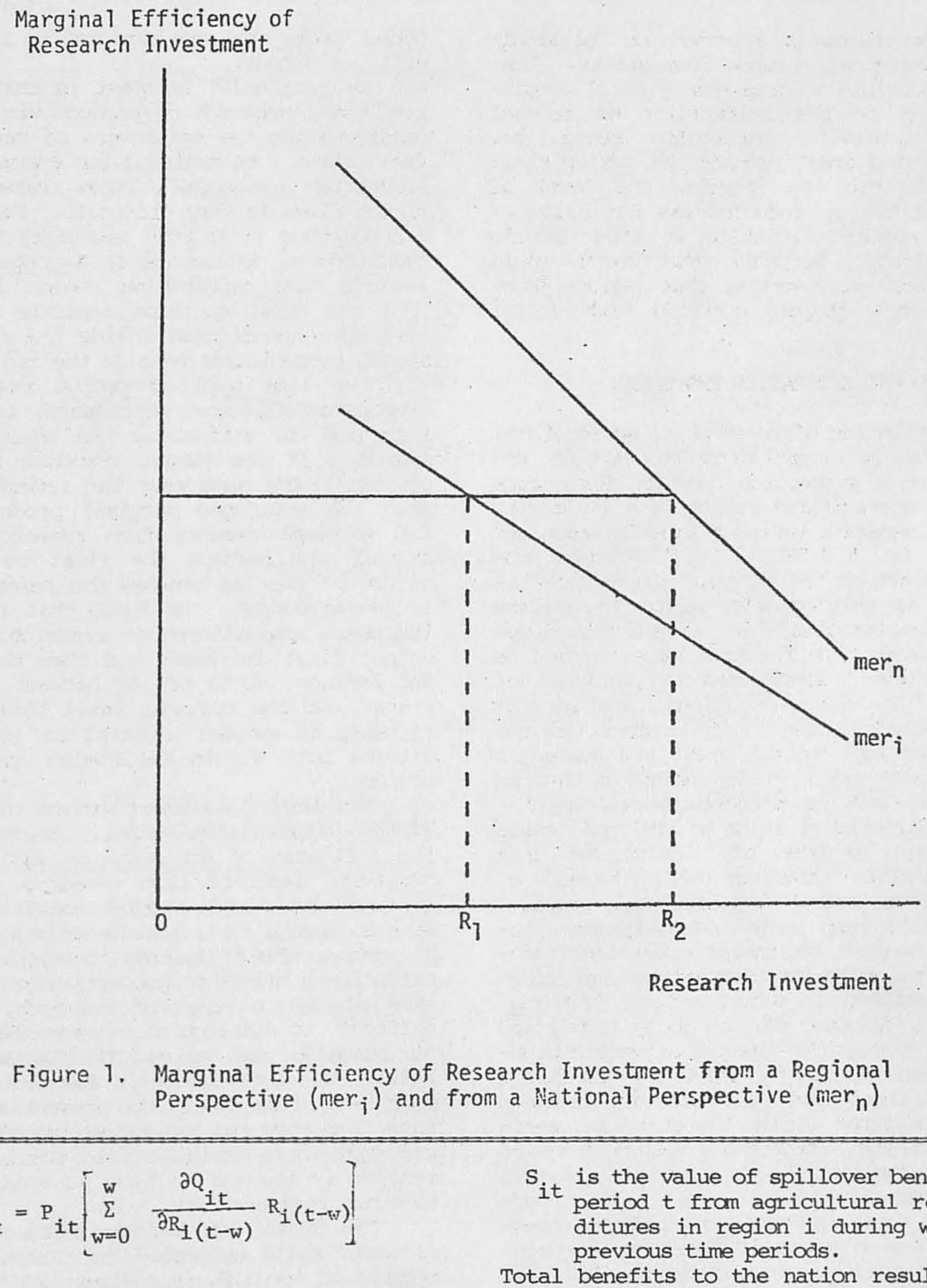

Figure 1. Marginal Efficiency of Research Investment from a Regional Perspective (mer_i) and from a National Perspective (mer_n)

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

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

Valuing benefits by this criterion is equivalent to paying resources 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:

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

where

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

Total benefits to the nation resulting from expenditures in region i are the sum of benefits to the originating region B_{it} and spillovers S_{it}. The relative importance of spillovers to regional benefits 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 to determine 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.

MODEL AND ESTIMATION PROCEDURE

The contribution of research to agricultural production has been estimated by several researchers using a production function for a commodity or the agricultural sector as a whole with research as a separate variable (see Peterson and Hayami, 1977, pp. 520-521). This approach provides an estimate of the marginal product of research which is particularly useful in guiding decisions. Most studies which have included research in a production function have focused on the national level rather than the regional or state levels. The only two national studies mentioned here are Griliches' (1964), which was the first published work in the area, and Evenson's (1967) work which revealed the nature of the lag between the research input and increased output.

Studies directed at state or regional levels 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 and 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 argues, 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.

In this paper the contribution of research to agricultural production is measured by estimating a production function which includes variables to reflect conventional inputs as well as agricultural research. Various outputs are aggregated into a single variable by using relative price weights. Input variables are similarly aggregated and thus abstract from quality differences that are not reflected in input prices. This estimation procedure controls for the use of other inputs that are expected to influence agricultural output.

Of particular interest is the effect of agricultural research on productivity, taking into consideration the spillovers of research results from region i to region j for every i and j. Accounting for such a large number of interregional flows is very difficult. Furthermore, for our purposes 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 contains separate variables for research expenditures inside the region and research expenditures outside the region.

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 is 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 effect on productivity can be considered similar to that of research, 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 effects to other regions.

The production function with one output and several inputs estimated for the ten production regions of the U.S. (see Figure 2) is the following Cobb-Douglas function expressed in log linear form:

$$(7)\quad \ln Q_{it} = \alpha_0 + \sum_{j=1}^{m} \alpha_1 \ln X_{ijt} + \gamma_1 \widetilde{RI}_{it} + \gamma_2 \widetilde{RO}_{it} + \varepsilon_{it}$$

where

- $\ln Q_{it}$ is the natural logarithm of the value of agricultural output per farm in region i and time period t,
- $\ln X_{ijt}$ is the natural logarithm of the per farm value of the j^{th} conventional input in region i and time period t,

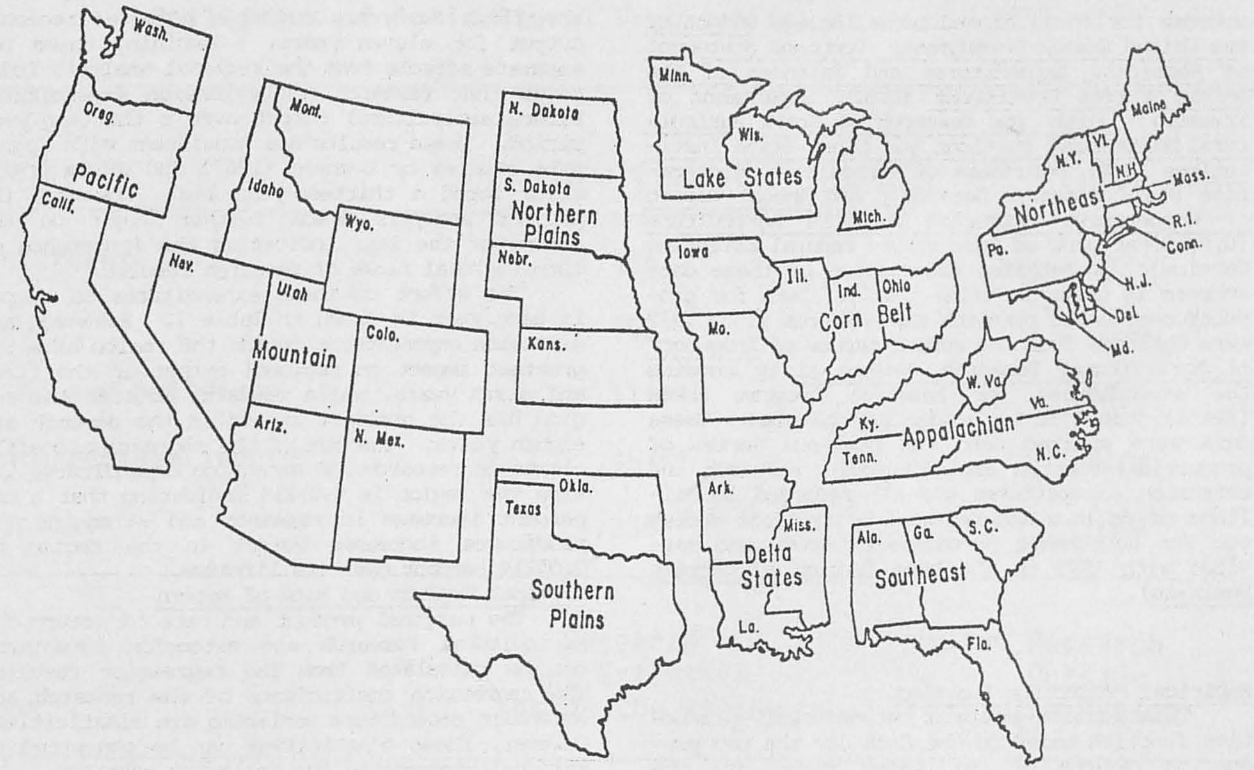

Figure 2. The Ten Farm Production Regions of the United States as Defined by the Economic Research Service, USDA

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

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

$\alpha_0, \alpha_1, \ldots, \gamma_1$, and γ_2 are regression parameters, and

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

The parameters of the equation were estimated using a generalized least squares procedure which estimates a first-order serial correlation coefficient for each region and adjusts for serial correlation in each region using the estimated regional serial correlation coefficient. After adjustment for serial correlation, the contemporaneous correlation among regions is corrected and the coefficients of the model are estimated.

DATA

Output and conventional inputs are specified on a per-farm basis and measured in constant 1972 dollars. Four conventional inputs are specified: labor, capital, land and buildings, and intermediate inputs. The agricultural output and intermediate input data were obtained from Farm Income Statistics. Agricultural output was the sum of farm cash marketings, government payments to farmers, value of home consumption of farmers, and net farm inventory change deflated by the index of prices received by farmers for all farm products. Intermediate inputs included expenditures for feed, livestock, seed, fertilizer, and lime and miscellaneous, which were deflated with the indexes of prices paid for feed, livestock, seed, fertilizer, and all items in production, respectively. The labor input was the total hours used for all farm work, as reported in Economic Indicators of the Farm Sector: Production and Efficiency Statistics (USDA), multiplied by the average wage rate to convert it to a dollar value. The capital variable, which includes interest and depreciation on mechanical power and machinery, repairs, licenses, and fuel, was calculated from data in Farm Income Statistics (USDA) and in Economic Indicators of the Farm Sector: Production and Efficiency Statistics (USDA). The value of land and buildings variable was from Agricultural Statistics (USDA) and was deflated by the consumer price index. All the price indexes were obtained from Agricultural Statistics (USDA) and had 1972 as the common base year.

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). A detailed description of these data sources is given in Cline (1975). Data for production-oriented research expenditures since 1972 were obtained from the annual issues of Inventory of Agricultural Research, Volume II by summing the expenditures for Research Program Areas (RPA's) judged to be production-oriented. These data were spliced onto the previous series of production-oriented expenditures. Research and extension expenditures are all recorded in millions of dollars and deflated by implicit deflator for government purchases of goods and services with 1972 as the base (Survey of Current Business).

RESULTS

Empirical Production Function

This section presents an empirical production function based on the data for the ten production regions of the United States for the period 1949-1981. The formulation quantifies the interregional spillovers of agricultural research results. Estimated regression coefficients and standard errors are shown in Table 1. The sign of each coefficient on conventional inputs are consistent with a priori knowledge. Each of these coefficients is also different from zero at the 0.01 level of significance. The elasticity of production is smallest for land and buildings and highest for intermediate inputs. 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 (7), the model 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 regional output immediately, indicating a more complicated lagged structure associated with these expenditures. Second-degree polynomials were estimated for expenditures both inside the region and outside the region.[2] The expenditure lags considered appropriate for this study were chosen from a large number of regression equations using different lags with the final choice based on minimum mean square error. Research and extension expenditures within the region affected regional output for eleven years. Research expenditures outside the region had no effect on regional output for the first two years and then affected regional output for eleven years. Combining these two separate effects from the regional analysis indicates that research and extension expenditures affect agricultural output over a thirteen year period. These results are consistent with aggregate studies by Evenson (1967) and Cline (1975) which found a thirteen-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 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 0.05214 indicating that a one percent increase in research and extension expenditures increases output in the region by 0.05214 percent over its lifetime.

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 of the research and extension expenditure variables are elasticities. However, these elasticities can be converted to marginal products by the following equation:

$$(8)\quad TMPR_i = \sum_{w=0}^{W} MPR_{i(t-w)} = \sum_{w=0}^{W} \beta_{(t-w)} (\bar{Q}_i/\bar{RI}_i)$$

where

- $TMPR_i$ is the marginal product of research and extension expenditure for region i aggregated over the lifetime of the investment,
- $MPR_{i(t-w)}$ is the marginal product of research and extension expenditure in region i and year (t-w)
- $\beta_{(t-w)}$ is the coefficient of the term in the polynomial lag which pertains to year (t-w),
- $\bar{Q}i$ is the mean level of agriculture output per state in region i, and
- $\bar{RI}_i$ is the mean level of research and extension expenditures per state in region i; both means are based on the 5-year period 1977-81.

The marginal products for research and extension expenditures for the ten production regions for the five year period 1977-81 are presented in Table 2. These estimates reflect the contribution of research and extension to regional output.

The Corn Belt and Northern Plains have the highest marginal products, \$9.55 and \$9.04 respectively, followed by the Southern Plains with a marginal product of \$8.38 per dollar invested in production-oriented agricultural research and extension. In contrast, the Northeast has the smallest marginal product of \$2.72, which is less

[2] 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.

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

Variable	Coefficient	Standard Error
Intercept	-1.465	.0035
Labor	.198**	.0074
Land and buildings	.114**	.0085
Intermediate inputs	.467**	.0104
Capital	.236**	.0099

Year	Research and Extension Inside the Region	Research Outside the Region
t	.000000	.000000
t-1	.002370	.000000
t-2	.004266	.000000
t-3	.005688	.003441
t-4	.006636	.006194
t-5	.007110	.008258
t-6	.007149	.009634
t-7	.006636	.010323
t-8	.005688	.010323
t-9	.004266	.009634
t-10	.002370	.008258
t-11	.000000	.006194
t-12	.000000	.003441
t-13	.000000	.000000
Sum	.052140 **	.075701**

R^2 = .99

**Statistically significant at the 0.01 level of significance.

Table 2. Regional Estimates of Benefits and Funding of Production-Oriented Agricultural Research and Extension: Averages for the 1977-81 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	Average Annual Spill-ins	Ratio of Federal-State Expenditures
	(Dollars)	(Percent)	---(Million Dollars)---			(Million Dollars)	
Northeast	2.72	23	254.23	839.04	3.30	368.88	1.03
Lake States	6.31	53	407.13	533.66	1.31	591.12	.67
Corn Belt	9.55	74	905.05	654.73	.72	1,314.15	.90
Northern Plains	9.04	71	482.05	449.33	.93	699.31	.56
Appalachian	3.63	31	309.87	685.00	2.21	449.29	.90
Southeast	3.68	32	292.02	663.98	2.27	423.49	.53
Delta	4.20	36	215.02	442.16	2.06	308.16	.64
Southern Plains	8.38	67	365.28	335.64	.92	530.00	.69
Mountain	5.18	44	312.42	544.91	1.74	453.26	.72
Pacific	6.03	51	495.86	708.99	1.43	719.78	.32
Aggregate	5.70	48	4,038.93	5,857.45	1.45	5,857.45	.68

than one-third the size of the marginal products of the Corn Belt and Northern Plains. The Appalachian, Southeast, and Delta regions also have relatively low marginal products. The "average" marginal product, which is estimated using national averages for agricultural output and research and extension expenditures is $5.70, indicating the aggregate return for one dollar invested in production-oriented agricultural research and extension.

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:

$$(9) \quad \sum_{w=0}^{W} MPR_{i(t-w)} \Big/ (1 + r_i)^w - 1 = 0$$

This procedure explicitly accounts for the lag structure. The regional rate of return for research and extension investments is also reported in Table 2. The average regional rate of return is 48 percent, and ranges from 23 percent in the Northeast to a high of 74 percent in the Corn Belt. 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 the study are considerably lower than the 30 to 180 percent rates which Evenson (1971) estimated for the same ten production 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 analysis. This may be explained at least in part 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 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 29 to 83 percent) for the originating region. Even the 29 percent for the Northeast compares 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:

$$(10) \quad B_i = \gamma_1(\bar{Q}_i/\overline{RI}_i)(\overline{RI}_i) = TMPR_i(\overline{RI}_i)$$

where:

B_i is the regional benefit for region i,

$_1$ is the regression coefficient of research and extension expenditures,

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

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

$TMPR_i$ is the marginal product of research expenditure 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 of marginal product. Calculating the regional spillovers, which is slightly more complicated, begins with the calculation of spill-ins (SI) for each region.

$$(11) \quad SI_i = \gamma_2(\bar{Q}_i/\overline{RO}_i)\overline{RO}_i = TMPRO_i(\overline{RO}_i)$$

where

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

$_2$ is the regression coefficient of the research expenditures outside of region i,

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

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

$TMPRO_i$ is the 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.

$$(12) \quad S_i = \sum_{k\neq i} SI_k \, (R_i / \sum_{i\neq k} R_i)$$

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

$\sum_{i\neq k} R_i$ 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 (10) and (12), respectively, are shown in Table 2.[3] These figures are annual averages for the 1977-1981 period reported in 1972 dollars. The estimated regional benefit is highest in the Corn Belt ($905.05 million) and lowest in the Delta region ($215.02 million). The estimated regional benefit in the Northeast is $254.23 million and is above benefits estimated for the Delta region.

With regard to spillovers of agricultural

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[3] 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.

research benefits to other regions, the Northeast generates the largest spillover (839.04 million). The Pacific, Corn Belt, Southeast, and Appalachian regions also generate relatively large spillovers; over $650 million annually. The Southern Plains, Northern Plains, and Delta regions generate some of the smallest spillovers.

The average ratio of spillovers to regional benefits for the 1977-1981 period is 1.45. The Corn Belt, Southern Plains, and Northern Plains regions have the smallest ratio of spillovers to regional benefits of 3.30, the largest of the ten production regions. The degree of diversity of agriculture will affect whether the research results of a region will be picked up by another region. The quality of research is critical with regard to spillovers. Two additional factors that are important are (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.

Estimates of average annual spill-ins into each of the ten production regions for the 1977-1981 period are presented in the second column from the right in Table 2. The Corn Belt has the largest spill-in of $1,314.15 million indicating that research results from other regions affect large volumes of crops and livestock produced in the Corn Belt. The Northeast has the second smallest average annual spill-in of $368.88 million (the Delta has only $308.16 million). In the Northeast the average annual spill-in is only 44 percent as large as the average annual spillover or spillout. In the Northeast, Appalachian, Southeast, Delta, and Mountain regions the spillovers exceeded the spill-ins during the 1977-1981 period. This indicates that agricultural research conducted in these regions affects outputs in other regions more than the outputs in these regions are affected by agricultural research conducted in other regions. This suggests that research conducted in other regions is not as readily applicable or that these regions with spill-ins lower than spillovers, for some reason, are not able to adapt agricultural research results from other regions.

The ratio of federal-to-state expenditures for agricultural research and extension presented in the far right column of Table 2 may be compared with the ratio of spillovers to regional benefits to determine whether the federal government actually financed the spillovers. The results indicate that except for the Corn Belt the federal government did not finance all of the spillovers in any of the ten regions during the 1977-1981 period. In an earlier analysis which utilized data only through 1972, White and Havlicek (1980) found that the federal government financed all the spillovers in the Northern Plains, Appalachian, and Mountain regions; however, during the last ten years, the federal government has reduced its relative share of funding of agricultural research and the states have had to pick up a larger share. Hence in the aggregate, the ratio of federal-to-state expenditures is only .68, as compared to 1.45 for the ratio of spillovers to regional benefits. Furthermore, except for the Northeast, the ratio of federal-to-state expenditures is less than one for each of the production regions. The Northeast, along with several of the other production regions, fares poorly in this in that the ratio of spillovers to regional benefits is over three times the ratio of federal-to-state funding. In the Southeast and Pacific regions the ratio of spillovers to regional benefits is over four times the ratio of federal-to-state funding. The federal government's contribution to production-oriented agricultural research and extension expenditures would have to be increased substantially to align regional funding with regional benefits, on the average. The Northeast would require one of the largest increases in federal support to improve the alignment of spillovers to regional benefits and federal-to-state expenditures. For the U.S. as a whole the results suggest that federal support would have to be more than doubled to align spillovers to regional benefits and federal-to-state expenditures.

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. The Northeast is a good example. In the Northeast, the marginal product and regional rate of return to public investment in production-oriented agricultural research and extension are low relative to some of the other production regions. The average annual regional benefit is also relatively low in comparison with some of the other production regions, but the average annual spillovers are relatively high, yielding a high ratio of spillovers to regional benefits. Relative to the ratio of spillovers to regional benefits, the ratio of federal-to-state expenditures is very low, indicating that the Northeast bears substantial costs of agricultural research benefits received by other production regions. This suggests that some kind of action by the federal government to increase funds for agricultural research through intergovernmental grants or other means seems appropriate 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. Possibly one of the benefits of this paper will be to stimulate other researchers to improve the measurement of spillovers and spillins of agricultural research results and improve our understanding of the transfer process and of financing agricultural research.

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