RSP 6: 1-16. ©1976 MCRSA. All rights reserved.

EFFICIENCY ASPECTS OF THE SPATIAL ALLOCATION OF PUBLIC SECTOR AGRICULTURAL RESEARCH AND EXTENSION IN THE UNITED STATES

Philip L. Cline and Yao-Chi Lu*

As Musgrave [16] has argued, public provision of certain goods and services is necessary to ensure allocative efficiency in a free-market economy when this economy is characterized by externalities including decreasing-cost industries and market imperfections. In view of Evenson's [6] observations regarding the ease of reproducibility of the most important technological changes in agriculture and the existence of significant economies of size in agricultural research, public sector involvement seems inescapable if the divergence between private gains from agricultural research and social benefits is to be minimized.

Tangible evidence of society's recognition of this role dates back to 1887 when passage of the Hatch Act set in motion the program of publicly supported agricultural research in the United States. This act provided federal funds for the establishment of an agricultural experiment station to act as the research component of the land-grant college in each state. Recognition of the role was further demonstrated by passage of the Smith-Lever Act in 1914 which created the Cooperative Extension Service and charged it with disseminating practical research findings to the farmers. In addition to these endeavors organized along state lines, various services of the U. S. Department of Agriculture also perform research having regional and national impacts. In 1972, expenditures by these three public agencies on research and extension activities aimed at increasing agricultural output per unit of aggregate input at the farm level, i.e., production-oriented research and extension (R&E) expenditures, totaled about $779 million.[1]

---

*Philip L. Cline is assistant professor at Washington and Lee University, and Yao-Chi is agricultural economist with the National Economic Analysis Division, ERS, USDA.

[1] Total public sector R&E expenditures in 1972 amounted to some $1,234 million. Of this total, $455 million was expended on nonproduction-oriented activities, i.e., R&E activities not aimed at increasing productivity at the farm level. These nonproduction-oriented expenditures were found to have an insignificant influence on agricultural productivity at the national level; they are therefore not included in the present study.

Several previous studies indicate that the rate of return to these large and growing public expenditures is sufficiently high to warrant continued investment [3, 5, 9]. However, little research has been done on the estimation and evaluation of rates of return by geographic regions of the country. In view of this lack of evidence, the principle aims of this paper are to estimate historical rates of return to public sector R&E expenditures for each of ten farm production regions[2] and to evaluate these returns on the basis of a spatial allocative efficiency condition. Due to lack of data, private sector R&E expenditures will not be included in this study.

A theoretical framework for measuring the rate of return to R&E is developed in the next section, followed by the corresponding empirical model and results. To evaluate these results an explicit criterion is then formulated. Summary and conclusions are presented in the final section of the paper.

Measuring the Contribution of R&E

While it is not particularly difficult to identify and measure the direct costs[3] of public sector agricultural R&E, estimating the benefits of these activities is not a simple task. One technique of estimating the benefits is to calculate the value of inputs saved by new and better production techniques. Two different approaches which utilize this basic idea have been applied by Schultz [17], and Tweeten and Hines [21].

The value of inputs saved technique sheds considerable light on the general relationship between the returns and the costs of agricultural R&E. Griliches [8], however, in his study of hybrid corn research brings somewhat more specificity to the problem by computing a rate of return to R&E. He estimates the returns by calculating the loss in consumer surplus to society which would occur had hybrid corn seed never been developed and adopted.

Both of the above techniques for estimating the benefits of public R&E activities result in estimates of average returns to past investments. By the nature of the budgetary process, however, decisions to invest in public R&E are made at the margin. It would therefore be desirable to have knowledge of the marginal rate of return to additional investment. As explained below, a production function technique is one method to obtain estimates of this marginal return. In addition, this technique allows one to estimate time lags

---

[2] The United States Department of Agriculture divides the United States into ten farm production regions: Northeast, Lake States, Corn Belt, Northern Plains, Appalachian, Southeast, Delta States, Southern Plains, Mountain, and Pacific. For the states in each region, see map on p. ii in Changes in Farm Production and Efficiency [22].

[3] The indirect costs of agricultural R&E are not known with any degree of certainty. The massive migration of the population from rural to urban areas is the major issue here.

in the research-extension-output relationship through various distributed lag techniques.

An early effort to introduce R&E expenditures directly into an aggregate agricultural production function was made by Griliches [9]. To allow for a lag in the effect of the R&E expenditures, he constructed the observations on the R&E variable by averaging the level of expenditures in the previous year and the level six years previously. The R&E as well as education variables were then included as factors of production along with other conventional inputs in the estimation of the parameters of the aggregate production functions. His results indicated that both R&E and education variables have a significant impact on the level of agricultural output.

Using a slightly different approach, Evenson [5] fitted a linear regression model to time series data of U. S. agriculture for the 1935-1963 period. A productivity index was employed as the dependent variable and the model explains its behavior by current values of public R&E expenditures, weather, and an index of educational attainment. Through a system of predefined weights, the effect of R&E was distributed through time in a manner which exhibits the shape of an inverted V.

Allen and Howitt [1] employed in a recent paper a more flexible lag technique to estimate the returns to research for California agriculture over the 1949-1969 period conditional on a normalized extension expenditure. In their model, output in the current period was specified as a logarithmic function of labor and capital in the current period, a given level of extension expenditures, and lagged values of research expenditures. A composite lag consisting of a polynomial lag and an exponential decay term was used by Allen and Howitt to estimate the impact of research on agricultural output in California.

In this study the following hypothesis is made concerning the lags between investment in R&E and its effects on agricultural productivity. Consider a single production-oriented research activity initiated in time t as shown in Figure 1. According to Griliches [7] and Evenson [5] this research activity will not immediately bear fruit in terms of improvements in the techniques of agricultural production. There is a time lag between the initiation of the research activity and its ensuing impact on productivity. From time t to time t + m research is being conducted, but no new technology is yet forthcoming from this research. In Marschak's [15] terminology, this is the "inquiry" or "data gathering" phase. The period t to t + m is normally composed of two lags: the lag between the time funds are invested in research and the time inventions actually begin to appear, and the lag between the invention of an idea or device and its development into a commercially applicable state [7, p. 20]. At time t + m, the research is effectively completed and its end product is an "extendable" technique. At this time, the extension of this knowledge begins and decisions upon actions on the basis of messages received are made at the farm level [15, p. 2]. As the new technology is adopted by farmers, technical change occurs and the contribution of R&E to productivity increases. The contribution to productivity will continue to increase as a result of the new technology as more and more farmers adopt it, and as early adopters extend their use of the affected inputs and gain experience in its application (time t + m to t + m + n). At some point, t + m + n, the contribution of this past R&E will reach a maximum, P_o. Then the value of the information will depreciate, according to Evenson [5] and Allen and Howitt [1] for any one of several reasons. First, it may become irrelevant. For example, the technology used in producing mule harnesses is still available; however, it no longer has any significant relevance for agricultural productivity. Second, the information may become obsolete as old inputs are replaced by superior or improved inputs. Third, the value of the technology may depreciate after some point in time due to biological decay. An example of this case is insects building up resistance to certain insecticides over time. Finally, changes in the relative prices of inputs may make the information economically obsolete. These types of phenomena are represented by the downward sloping portion of the curve in Figure 1. The form of the total lag between production-oriented R&E activity and its contribution to agricultural productivity is given by the convolution of these individual lags.

Based upon these observations, the theoretical model for estimating the contribution of R&E is specified as:

$$P_t = f\,(R_t, R_{t-1}, \ldots, R_{t-n}, E_t, W_t)$$

where

P_t is the value of an aggregate productivity index for agriculture in time t

R_{t-i} is a distributed lag function of public sector R&E in the current period and n preceding periods[4]

E_t is the value in the current period of an index of educational attainment of farmers and farm laborers

W_t is the value in the current period of a weather index

To select the algebraic form of the model, several alternative forms including linear and semi-logarithmic forms have been considered. Our results indicate that the Cobb-Douglas form fits the data better than any other forms we have considered. Therefore, the following Cobb-Douglas model was selected:

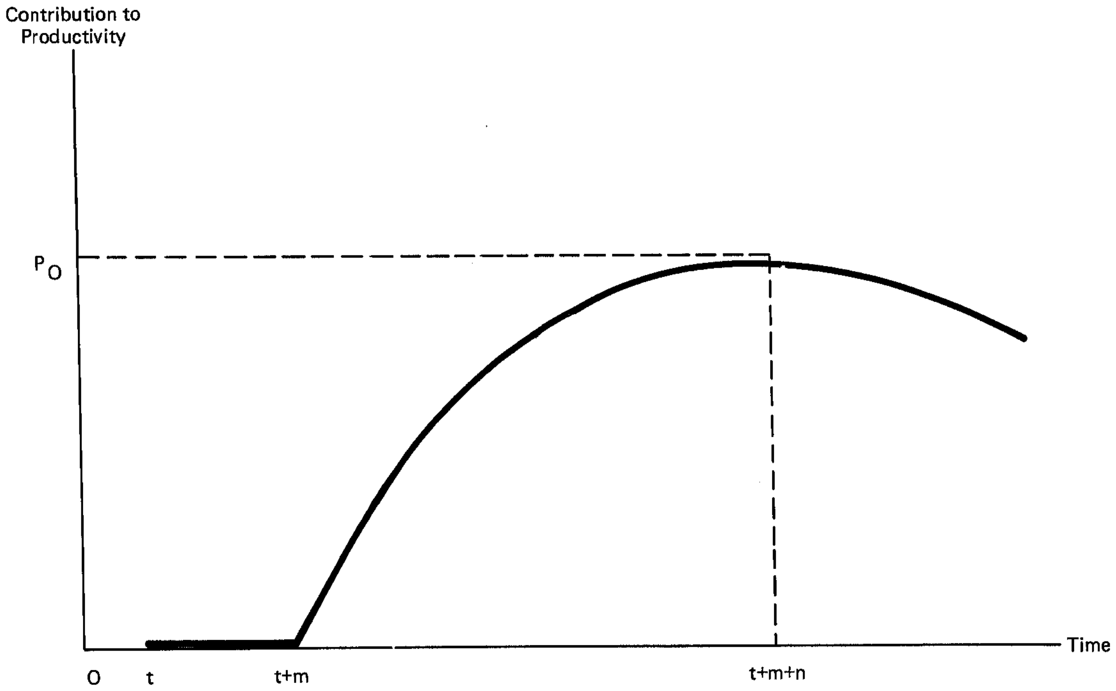
$$(1)\quad P_t = \prod_{i=0}^{n} R_{t-i}^{\beta_i}\, E_t^{\beta_{n+1}}\, e^{\beta_{n+2} W_t}$$

The form which the weather variable enters Equation (1) is unusual and thus an explanation is in order. In a study of the response of grain yields to weather, Thomason [20] found that the relationship between yields and weather is curvilinear.

---

[4] To allow for the inquiry lag (time t to t + m in Figure 1) observations on R were constructed as extension expenditures in the current time period plus research expenditures in the previous period.

FIGURE 1: The Effect of Production-Oriented Research and Extension Activity on Productivity.



The elasticity of yields with respect to the weather index is not constant. Instead, the elasticity varies with the value of the weather index. Thus, the relationship between yield (y) and weather can be represented by $y = e^{\beta W}$, where the elasticity of yield with respect to weather is βW.

Estimation Procedures

To estimate Equation (1), data for each of the ten regions were assembled for the 1939 to 1972 period. Productivity indexes[5] for the 1950 to 1972 period are from the 1964 and 1973 issues of Changes in Farm Production and Efficiency [22]. Data for the 1939 to 1949 period are from Lambert [11]. Research and extension expenditures are from Cline [3] and education indexes are constructed from a series reported by Evenson [5]. Weather indexes are constructed from Stallings [18] and Kost [10] under the hypothesis that variations in yields of crops where as many variables as possible are held constant over time are attributable to the influence of weather after the trend has been removed to account for changes in the fertility level of the soil. A detailed explanation of all data series can be found in Cline [3, pp. 139-174].

A common practice is to use ordinary least squares to fit Equation (1) to time series data in the natural logarithmic form:

$$(2) \quad \ln P_t = \sum_{i=0}^{n} \beta_i \ln R_{t-i} + \beta_{n+1} \ln E_t + \beta_{n+2} W_t + u_t$$

where u_t is the disturbance term. However, this procedure often violates two basic assumptions of the ordinary least squares estimation procedure. The most serious violation is the lack of independence of the disturbance terms, which arises from the correlation between time periods of the values of excluded variables. The second violation concerns high correlations between the independent variables. As a result of this violation, multi-collinearity becomes potentially serious which in turn produces least-squares estimators with unusually large variances.

In view of these potential violations of the ordinary least squares estimation procedure, the Durbin two-stage procedure [4] was employed to estimate an autocorrelation parameter for each region. The first order autoregression model specified in Equation (3) was then estimated using the Almon distributed

---

[5] The productivity index used in this study is computed by taking the ratio of the value of farm output to an aggregate input which represents all the resources used in the production process. The aggregate input is obtained by combining all inputs arithmetically using factor prices as weights. A detailed description about this method and an alternative measure of productivity using a production function approach can be found in Lu [14].

lag technique:

$$(3)\quad \ln P_t - \rho \ln P_{t-1} = \sum_{i=0}^{n} \beta_i (\ln R_{t-1} - \rho \ln R_{t-i-1}) + \beta_{n+1} (\ln E_t - \rho \ln E_{t-1}) + \beta_{n+2} (W_t - W_{t-1}) + e_t$$

where $e_t = u_t - \rho u_{t-1}$. Various lag lengths ranging from 7 through 17 years were estimated for two cases: (1) no endpoint constraints were imposed and (2) the endpoints were constrained to approximately equal zero. The degree of polynomial by which the weights of the R&E variable were restricted was varied from two to four.

In spite of following the Durbin procedure, the attempt to fit Equation (3) to annual data for each of the ten farm production regions was thwarted by high collinearity between the education variable and the R&E variable.

To overcome this difficulty, an estimate of the education parameter obtained from fitting national data to Equation (3) was incorporated into the model. The fitted equation for each of the regions is therefore shown by the following:

$$(4)\quad (\ln P_t - \rho \ln P_{t-1}) - [0.78 (\ln E_t - \rho \ln E_{t-1})] = \sum_{i=0}^{n} \beta_i (\ln R_{t-1} - \rho \ln R_{t-i-1}) + \beta_{n+1} (W_t - \rho W_{t-1}) + e_t$$

where 0.78 is the predetermined coefficient of the education variable and the endpoints of the distributed lag weights are constrained to approximately equal zero.[6]

The results from fitting Equation (4) to the annual regional data are reported in Table 1. Only the "best" lag length and degree of polynomial (two in all cases) as determined by Theil's [19] minimum standard error of estimate criterion is reported for each region.

For each of the regions R&E expenditures affect productivity over time in a manner that is consistent with the hypothesized time form. A joint F test for each region of the null hypothesis that all the regression coefficients for the R's are equal to zero was rejected at the one percent level of significance in all cases. The coefficient of the weather variable is also of the

---

[6] Footnote on page 10.

TABLE 1: Equation (4) Regression Results

Explanatory Variable	Region				
	North-east	Lake States	Corn Belt	Northern Plains	Appala-chian
$\dot{W}_t - \hat{\rho} W_{t-1}$	0.0023 (3.7442)	0.0014 (2.2904)	0.0039 (7.6164)	0.0042 (13.7280)	0.0036 (5.0758)
$R_t - \hat{\rho} R_{t-1}$	0.0009	0.0012	0.0007	0.0007	0.0011
$R_{t-1} - \hat{\rho} R_{t-2}$	0.0017	0.0023	0.0013	0.0013	0.0020
$R_{t-2} - \hat{\rho} R_{t-3}$	0.0023	0.0032	0.0018	0.0017	0.0028
$R_{t-3} - \hat{\rho} R_{t-4}$	0.0029	0.0039	0.0022	0.0021	0.0034
$R_{t-4} - \hat{\rho} R_{t-5}$	0.0033	0.0045	0.0025	0.0024	0.0039
$R_{t-5} - \hat{\rho} R_{t-6}$	0.0035	0.0049	0.0027	0.0025	0.0042
$R_{t-6} - \hat{\rho} R_{t-7}$	0.0036	0.0051	0.0028	0.0026	0.0044
$R_{t-7} - \hat{\rho} R_{t-8}$	0.0036	0.0052	0.0028	0.0025	0.0044
$R_{t-8} - \hat{\rho} R_{t-9}$	0.0035	0.0051	0.0027	0.0024	0.0042
$R_{t-9} - \hat{\rho} R_{t-10}$	0.0033	0.0049	0.0025	0.0021	0.0039
$R_{t-10} - \hat{\rho} R_{t-11}$	0.0029	0.0045	0.0022	0.0017	0.0034
$R_{t-11} - \hat{\rho} R_{t-12}$	0.0023	0.0039	0.0018	0.0013	0.0028
$R_{t-12} - \hat{\rho} R_{t-13}$	0.0017	0.0032	0.0013	0.0007	0.0020
$R_{t-13} - \hat{\rho} R_{t-14}$	0.0009	0.0023	0.0007		0.0011
$R_{t-14} - \hat{\rho} R_{t-15}$		0.0012			
$\sum_{i=0}^{n} \beta_i^{b}$	0.0365	0.0551	0.0280	0.0239	0.0438
$\bar{R}^2$	0.9111	0.9833	0.9859	0.9904	0.9912
SEE^c	0.03315	0.02595	0.03393	0.02851	0.03608
DW^d	2.29	2.08	1.89	2.08	2.16
$\hat{\rho}^e$	0.829	0.713	0.576	0.579	0.686

TABLE 1: Continued

Explanatory Variable	Region				
	South-east	Delta States	Southern Plains	Mountain	Pacific
$W_t - \rho W_{t-1}$	0.0038 (5.4282)	0.0027 (6.4858)	0.0049 (8.7224)	0.0018 (4.9086)	0.0003 (0.7784)
$R_t - \rho R_{t-1}$	0.0009	0.0018	0.0005	0.0018	0.0030
$R_{t-1} - \rho R_{t-2}$	0.0017	0.0032	0.0010	0.0033	0.0054
$R_{t-2} - \rho R_{t-3}$	0.0023	0.0044	0.0014	0.0044	0.0072
$R_{t-3} - \rho R_{t-4}$	0.0029	0.0052	0.0017	0.0052	0.0084
$R_{t-4} - \rho R_{t-5}$	0.0033	0.0056	0.0019	0.0057	0.0090
$R_{t-5} - \rho R_{t-6}$	0.0035	0.0058	0.0020	0.0059	0.0090
$R_{t-6} - \rho R_{t-7}$	0.0036	0.0056	0.0021	0.0057	0.0084
$R_{t-7} - \rho R_{t-8}$	0.0036	0.0052	0.0021	0.0052	0.0072
$R_{t-8} - \rho R_{t-9}$	0.0035	0.0044	0.0020	0.0044	0.0054
$R_{t-9} - \rho R_{t-10}$	0.0033	0.0032	0.0019	0.0033	0.0030
$R_{t-10} - \rho R_{t-11}$	0.0029	0.0018	0.0017	0.0018	
$R_{t-11} - \rho R_{t-12}$	0.0023		0.0014		
$R_{t-12} - \rho R_{t-13}$	0.0017		0.0010		
$R_{t-13} - \rho R_{t-14}$	0.0009		0.0005		
$R_{t-14} - \rho R_{t-15}$					
$\sum_{i=0}^{n} \beta_i$ [b]	0.0364	0.0461	0.0211	0.0469	0.0662
$\bar{R}^2$	0.9774	0.9237	0.9940	0.9937	0.9975
SEE[c]	0.03965	0.04176	0.03979	0.02238	0.01927
DW[d]	2.07	2.15	1.74	1.84	1.45
ρ[e]	0.640	0.828	0.291	0.577	0.463

[a] Numbers in parentheses are t-values; all exceed the critical t value at the one percent level.

[b] A joint F test of the null hypothesis that all the regression coefficients for the R's are equal to zero was rejected at the one percent level of significance.

[c] Standard error of the estimate.

[d] Durbin-Watson "d" statistic.

[e] The estimated value of the first-order autoregression coefficient of the disturbances.

expected sign for all regions and is significant at the one percent level for every region except the Pacific region. The coefficients of multiple determination are .91 or greater, and Durbin-Watson tests for autocorrelation indicate rejection of the hypothesis of positive autocorrelation at the 5 percent level of significance for six of the ten regions. For the remaining regions, the test is inconclusive.

Regional Rates of Return to R&E

Given the specification of the model shown in Equation (4), each individual distributed lag coefficient is a direct estimate of the elasticity of agricultural productivity with respect to R&E expenditures in the appropriate time period. That is,

$$\beta_i = \frac{\Delta P_t}{\Delta R_{t-i}} \cdot \frac{R_{t-i}}{P_t}$$

or

$$\frac{\Delta P_t}{\Delta R_{t-i}} = \frac{P_t}{R_{t-i}} \beta_i$$

which represents the increase in productivity in response to a one dollar increase in R_{t-i}. To approximate the marginal products (MP) of R_{t-i}, the ratio of the average level of productivity to the average level of R&E expenditures over the time period in question was substituted for P_t/R_{t-i}:

---

[6] The distributed lag weights generated by the unrestricted (no endpoint constraints) autoregression model do not entirely conform to the theoretical framework. Specifically, the coefficients generated by this model include negative weights, implying that the contribution of production-oriented research and extension expenditures to agricultural productivity is negative over part of its lifetime. In view of this, Equation (3) was also estimated using national data under the assumption that the endpoints of the time form are approximately equal to zero. The "best" lag length (minimum standard error of estimate) for both the unrestricted and the restricted model was then identified (13 years in both cases) and the appropriateness of the endpoint constraints was tested using the following F statistic:

$$F_{m,\ T-K} = \frac{SSE(\hat{\beta}) - SSE(B)}{m} \div \frac{SSE(B)}{T-K}$$

where $SSE(\hat{\beta})$ is the calculated error sum of squares obtained by estimating the restricted autoregression model; SEE(B) is the calculated error sum of squares from the unrestricted model; m is the dimension of the array of endpoint constraints; T is the number of observations, and K is the number of independent variables. The null hypothesis that the endpoint constraints are appropriate was not rejected on the basis of this test; the calculated F value was only 0.085, far below the appropriate critical point of the F distribution at the one percent level of significance.

$$(5)\quad \frac{\Delta P_t}{\Delta R_{t-i}} = \frac{\bar{P}}{\bar{R}} \beta_i$$

where a bar over a variable name indicates the average of that variable. Since it is desirable to know the increase in agricultural output brought about by a one dollar increase in R_{t-i}, the result obtained in Equation (5) must be adjusted by converting the numerator, ΔP_t, to its equivalent in terms of agricultural output (Y_t). This conversion can be made by multiplying Equation (5) by the average net increase in the value of output over the period due to a one point increase in productivity:

$$\frac{\Delta P_t}{\Delta R_{t-i}} \cdot \frac{\Delta Y_t}{\Delta P_t} = \frac{\Delta Y_t}{\Delta R_{t-i}} \simeq MP_{t-i}$$

where ΔY_t is the increase in the value of agricultural output net of increases in the value of inputs.

One measure of the rate of return to investment in R&E expenditures is the marginal internal rate of return, i.e., that rate of return, r, which results in

$$1 - \sum_{i=0}^{n} \frac{MP_{t-i}}{(1+r)^i} = 0 .$$

The results of calculating r's for each of the regions are presented in the second column of Table 2. However, these measures of the return to R&E are subject to a common bias resulting from a failure to include the contribution of private sector R&E in the model. Since private R&E data are not accessible except in a very few instances, the actual bias in the R coefficient cannot be known. Using the limited data available, however, Evenson [5] has estimated that the effect of private R&E is to bias the contribution of public R&E upward by a factor of 1.22. Adjusting the R coefficients by this factor in an attempt to derive an estimate of the return to public sector R&E results in the adjusted marginal internal rates of return shown in the third column of Table 2.

Evaluation of Regional Rates of Return

Within the analytical framework of modern welfare economics as synthesized by Bator [2] and extended by Musgrave [16], the determination of a welfare optimum requires the economic system to provide simultaneously an equitable distribution of income and an efficient allocation of resources among all alternative uses at all alternative locations. These two conditions are fundamentally interdependent. Due in large part to this interdependency, one often encounters serious obstacles in the use of this framework to examine actual institutions and programs; in the area of public finance, for example, it is frequently very difficult to disentangle the allocative and redistributive effects of any given fiscal program.

TABLE 2: Marginal Internal Rates of Return (in Percentages) to Production-Oriented Research and Extension Expenditures for Ten Farm Production Regions of the United States

Region	Rate of Return[a]	Adjusted Rate of Return[b]
Northeast	20.0	16.4
Lake States	43.0	35.2
Corn Belt	33.5	27.4
Northern Plains	28.5	23.4
Appalachian	28.0	23.0
Southeast	18.5	15.2
Delta States	33.5	27.5
Southern Plains	17.5	14.3
Mountain	27.5	22.5
Pacific	54.0	44.3

[a] The estimated rate of return without adjustment for bias caused by a failure to include private sector research and extension expenditures in the model.

[b] The estimated rate of return adjusted for private sector research and extension expenditures.

Nevertheless, the framework suggests a standard of efficiency against which the effects of time-honored methods of allocating public sector R&E expenditures can be compared. This standard can be stated as the need to equalize the return to agricultural R&E expenditures between the ten farm production regions. In other words, if it is found that there are significant differences in the rates of return between the regions, then those regions with relatively high rates of return should receive relatively large R&E expenditures.

It is apparent from Table 2 that significant differences in the rates of return to public R&E exist. The adjusted internal rates of return vary from a high of 44.3 percent in the Pacific region to a low of 14.3 percent in the Southern Plains. Therefore, purely from an efficiency point of view, the Pacific and Lake States regions are prime candidates for relatively greater R&E expenditures, while investments in the Southern Plains, Southeast, and Northeast regions earn a relatively poor rate of return and these regions should therefore undertake smaller R&E expenditures relative to the other regions.

A number of caveats are in order should one be tempted to take this standard of allocative efficiency too literally. First, it should be pointed out that the standard totally ignores considerations of equity. Also, the standard merely asserts that the return to R&E should be equalized between regions; it says nothing about the return to factors engaged in the production of agricultural R&E relative to the return which they might earn in alternative capacities. Still another warning concerns the piecemeal satisfaction of welfare optimum conditions. As Lipsey and Lancaster [13] have demonstrated with their theory of second-best, it does not follow that society's economic well-being is necessarily enhanced by such activity. Finally, it should be clear that each of the ten production regions does not operate in isolation. Interregional flows of R&E results undoubtedly occur to some extent (See Latimer [12] on this subject). It is also quite likely, however, that research is approximately equally pervasive in all directions. In this case the estimated relative returns to R&E between the regions would retain an acceptable level of validity. In light of these considerations, the standard of allocative efficiency should be viewed as a guide for recognition of extreme misallocations of R&E resources.

Summary and Conclusions

The objective of this paper was to estimate historical rates of return to public sector R&E expenditures for each of ten farm production regions. To accomplish this objective, a model that related the historical behavior of agricultural productivity in each region to current and past R&E expenditures, the level of educational attainment of farmers, and weather was hypothesized. The results of estimating this model for the 1939 to 1972 period indicate that the rates of return to public R&E vary from a high of 44.3 percent in the Pacific Region to a low of 14.3 percent in the Southern Plains Region.

To evaluate these returns, the spatial allocative efficiency condition suggested by modern welfare economics was adopted as a criterion, i.e., rates of return should be equalized between the ten regions. Based upon the results of this study, it can be concluded that historical methods of allocating R&E expenditures among the regions have not resulted in a distribution of resources that adequately reflects the allocative efficiency standard suggested above. In fact, there would seem to be considerable room for improvement; the coefficient of variation for the ten rates of return is over 30 percent. Reallocation of R&E expenditures from the regions with relatively low rates of return to the regions with higher rates of return would yield a higher return to the total R&E investment.

REFERENCES

1. Allen, P. G., and R. E. Howitt. "The Allocation of Research and Extension Expenditures in Agriculture." Paper presented at American Agricultural Economics Association annual meeting, August, 1974.

2. Bator, Francis M. "The Simple Analytics of Welfare Maximization." American Economic Review, March 1957, 385-413.

3. Cline, Philip L. "Sources of Productivity Change in United States Agriculture." Ph.D. dissertation, Oklahoma State University, 1975.

4. Durbin, J. "Estimation of Parameters in Time-Series Regression Models." Journal of the Royal Statistics Society, Series B, 22, January 1969, 139-153.

5. Evenson, Robert E. "The Contributions of Agricultural Research and Extension to Agricultural Productivity." Ph.D. dissertation, University of Chicago, 1968.

6. Evenson, Robert E. "Evaluation of Agricultural Research Productivity." Journal of Farm Economics, 49, December 1967, 1415-1425.

7. Griliches, Zvi. "Distributed Lags: A Survey." Econometrica, 35, January 1967, 16-49.

8. Griliches, Zvi. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." Journal of Political Economy, 66, October 1958, 419-431.

9. Griliches, Zvi. "Research Expenditures, Education, and the Aggregate Agricultural Production Function." The American Economic Review, 54, December 1964, 961-974.

10. Kost, William E. "Weather Indexes 1950-1963." Quarterly Bulletin of Michigan Agricultural Station, 47, August 1964, 18-42.

11. Lambert, L. D. "Regional Trends in the Productivity of American Agriculture." Ph.D. dissertation, Michigan State University, 1973.

12. Latimer, R. G. "Some Economic Aspects of Agricultural Research and Education in the United States." Ph.D. dissertation, Purdue University, 1964.

13. Lipsey, R. G. and K. Lancaster. "The General Theory of Second Best." Review of Economic Studies, 1956.

14. Lu, Yao-Chi. "Measuring Productivity Change in U. S. Agriculture," Southern Journal of Agricultural Economics (forthcoming).

15. Marschak, Jacob. "Economics of Inquiring, Communicating, Deciding." American Economic Review, 58, May 1968, 1-18.

16. Musgrave, Richard. The Theory of Public Finance. New York: McGraw-Hill, 1959.

17. Schultz, T. W. The Economic Organization of Agriculture. New York: McGraw-Hill, 1953.

18. Stallings, J. L. "Indexes of the Influence of Weather on Agricultural Output." Ph.D. dissertation, Michigan State University, 1958.

19. Theil, H. Economic Forecasts and Policy, 2d. ed. Amsterdam: North Holland Publishing Company, 1961.

20. Thomason, Louis M. "Weather Variability and the Need for a Food Resource." Center for Agricultural Economic Development, Iowa State University, Report No. 25, 1966.

21. Tweeten, Luther G., and Fred K. Hines. "Contributions of Agricultural Productivity to National Economic Growth." Agricultural Science Review, 3, Second Quarter 1965, 40-45.

22. U. S. Department of Agriculture. Economic Research Service. Changes in Farm Production and Efficiency. Statistical Bulletin No. 233. Washington, D. C.: Government Printing Office, 1964 and 1973.