ESTIMATING EFFECTS OF AGRICULTURAL RESEARCH AND EXTENSION EXPENDITURES ON PRODUCTIVITY: A TRANSLOG PRODUCTION FUNCTION APPROACH

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Abstract

The effects of agricultural research and extension expenditures on productivity in the United States are estimated during the period 1949-81 using data for ten production regions. The large time-series cross-sectional data base allows the translog production function to be estimated directly. Results from the translog and Cobb-Douglas production functions are compared. The results indicate that use of the Cobb-Douglas production function would overestimate the internal rate of return of agricultural research and extension expenditures in the United States and eight production regions. The total marginal product and internal rate of return for the United States are $8.11 and 66 percent, respectively.

Key words: agricultural research, agricultural extension, productivity, translog production function.

Agricultural productivity in the United States increased rapidly over the last half century. However, much concern has been expressed recently over a possible slowdown in this growth rate. In order to explain such variations in productivity growth, numerous attempts have been made to model the processes of technological change. A better understanding of these processes is needed in order to forecast shifts in agricultural productivity as a result of changes in such exogenous factors as research and extension investment.

While several approaches could be used, it is generally recognized that the production function approach is best for examining effects of research on the relative productivity of inputs (Norton and Davis). Previous research efforts estimating such production functions used restrictive formulations that may have biased results. Most notably, the Cobb-Douglas production function, which assumes separability among inputs, has traditionally been used. The restrictions imposed by such specifications can be tested using flexible production functions (Ray).

The purpose of this paper is to estimate an aggregate production function for United States agriculture using a flexible production function formulation. A comparison of the results from the flexible production function will be made with those from the more traditional Cobb-Douglas formulation. More specifically, the paper will apply translog and Cobb-Douglas production functions to: (1) estimate the effects of agricultural research and extension expenditures on productivity and (2) measure marginal returns to agricultural research and extension. Results from the alternative model specifications will be contrasted to evaluate potential biases.

A REVIEW OF THE PRODUCTION FUNCTION APPROACH

Agricultural research and extension (R & E) has been regarded as a major source of technological change. Hence, its role in the agricultural production process has attracted much attention in recent years (Peterson and Hayami). A change in R & E investment would be expected to produce quality changes in inputs and hence affect the productivity of inputs, which in turn would affect input-output relationships. Several methods have been developed to evaluate these impacts with the most widely adopted method in *ex post* evaluation studies being the production function approach. With this approach, the R & E variables are inserted directly into the production function in order to measure the impacts of R & E on output (Griliches; Peterson and Hayami). A major advantage of this approach is that it provides estimates of the marginal products (MP) of research and extension, as well as marginal products of other variables affecting input quality. The basic model used by the production function approach can be written as:

$$(1)\ Q_t = \alpha_1 \cdot \prod_{i=1}^{m} X_{it}^{\beta_i} \prod_{j=0}^{n} R_{t-j}^{\gamma_j} e^{u},$$

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where:

Q_t = value of output in year t,
X_{it} = value of i^{th} conventional input in year
R_{t-j} = research and extension expenditures in the $t-j^{th}$ period, α, β_i's, and γ_j's = parameters, and
u = disturbance term.

Research and extension expenditures in 1 year may also affect productivity over a period of several years. Initially, the contribution of research is small, but as research results become available and are adopted by more producers, the contribution to productivity will increase for a number of years. After a longer period, the impact of the improvement may be eroded. Evenson reported that agricultural experiment station research in the United States affected productivity for a total of 12 to 15 years. Cline and Lu et al., using aggregate United States data, concluded that production-oriented R & E investment affected productivity for 13 years.

Including R & E expenditures for several years in the production function would increase the possibility of multicollinearity problems, which would result in imprecise estimates and probably unreliable results. To overcome this problem, an inverted "V"—or "U"—shaped distributed lag assumption was imposed on the R & E variables to reduce the number of parameters to be estimated (Evenson; Cline; and White and Havlicek).

Most of the studies using the production function approach specify a Cobb-Douglas production function. This functional form assumes homogeneity, unitary elasticity of substitution between inputs, and separability. Griliches tested the assumption of unitary elasticity of substitution between labor and all other inputs for aggregate United States agriculture and concluded that the Cobb-Douglas function form was appropriate. For other studies, the Cobb-Douglas function has been chosen mainly for its simplicity. In the case of two factors of production, the Cobb-Douglas function has proven to be useful in empirical analysis. For more than two factors of production, the assumption of constant elasticity for substitution requires highly restrictive conditions on the elasticity values, which would make the assumption untenable (McFadden). In addition, the assumptions of homogeneity and separability impose more restrictions on the technology of production, which would bias the estimates if the true functional form is not a Cobb-Douglas function. As Bredahl and Peterson recognized: *"agricultural production functions are probably not homothetic, much less homogeneous"* (p. 684). Vincent also found that the agricultural production function in Australia is neither Cobb-Douglas nor exhibits constant elasticity of substitution.

Use of so-called "flexible" functional forms in estimating production functions can eliminate problems associated with these restrictive assumptions. The basic characteristics of the class of flexible functional forms is that they provide a second order approximation to any arbitrarily twice differentiable function. One of the functional forms belonging to this class is the translog (transcendental logarithm) function, which was proposed by Christensen, Jorgenson, and Lau (1971, 1973). The translog function does not employ separability and homogeneity as part of the maintained hypothesis, neither does it assume constant or unitary elasticity of substitution between inputs. Rather, the separability and homogeneity assumptions can be tested and the values of the elasticity of substitution vary for every data point in input space. Although the translog functional form has these advantages, there are some limitations. First, the translog function does not always provide a good approximation over a wide range of observations (Wales). The curvature conditions of the production function (monotonicity and quasi-concavity) can be violated even though the approximating function fits the data very well. This, however, does not necessarily imply the absence of an underlying profit-maximizing process of the production function, but simply reflects the inability of the functional form to approximate the true function over the range of the data. Secondly, if used as an exact form, the translog functional forms are inflexible in providing a second-order approximation to an arbitrary weakly separable function[1] (Blackorby et al.).

Use of the translog production function involves estimation of more parameters than the Cobb-Douglas production function. In the case of one output and five inputs, as specified in this study, the translog production function would have twenty-one explanatory variables, including an intercept. It is difficult to efficiently estimate the parameters directly with small samples, because of possible multicollinearity problems. One way to mitigate this prob-

[1]Let N denote the set of n inputs, i.e., $N = \{1, ..., n\}$ and t be a partition of N, $N = \{N_1 U N_2 ... U N_t\}$. $N_r \cap N_s = \Phi$ for $r \neq s$. A production function f is weakly separable if $f_j f_{ik} - f_i f_{jk} = 0$ for all i, j $\notin N_r$ and k $\notin N_r$ (Fuss et al.).

lem is to increase sample size.[2] This analysis covers 10 production regions[3] and 33 years (1949-81), which provide 330 observations and allows needed degrees of freedom for estimation of the model.

THE MODEL

The translog production function with one output and n inputs for the production regions can be specified as follows:

$$(2)\ \ln Q_{kt} = \alpha_k + \alpha_T \bullet \ln T_{kt} + \sum_{i=1}^{n} \alpha_i \bullet \ln X_{ikt} + \frac{1}{2} \bullet \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln X_{ikt} \ln X_{jkt} + \sum_{i=1}^{n} \gamma_{iT} \bullet \ln X_{ikt} \ln T_{kt} + \frac{1}{2} \bullet \gamma_{TT} (\ln T_{kt})^2 + e_{kt},$$

where:

- $\ln Q_{kt}$ is the natural logarithm of the value of agricultural output per farm in region k and time period t,
- $\ln X_{ikt}$ is the natural logarithm of the per farm value of the i^{th} conventional input in region k and time period t,
- $\ln T_{kt}$ is the natural logarithm of the technology index of region k and time period t,
- e_{kt} is the disturbance term associated with t^{th} observation in region k,
- α_k, α_T, α_i, γ_{ij}, γ_{iT}, γ_{TT} are regression parameters, and
- $k = 1, 2 \ldots, 10;\ i, j = 1, 2, 3, 4.$

Four conventional inputs were specified: labor (L), land and buildings (A), capital (C), and intermediate inputs (F). Capital includes interest and depreciation on mechanical power and machinery, repairs, licenses, and fuel. Intermediate inputs are composed of feed, seed, livestock, fertilizer, lime and miscellaneous.

The technology index was represented by R & E expenditures per state with a 13-year lag and a second-degree polynomial (an inverted "U" shape) function following results from Cline and White and Havlicek. That is,

$$(3)\ T = \prod_{j=0}^{13} R_{t-j}^{\gamma_j},$$

where R is R & E expenditures and γ_j's follow a second degree polynomial distributed lag with both end points restricted at zero. Measuring the influences of extension expenditures on agricultural productivity separate from research expenditures has been difficult. If extension's role is distinct from that of research, a separate extension variable should be used in the production function. However, if extension's role can be viewed as improving the quality of labor and other inputs, 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, p. 1421). The latter case is assumed to be the appropriate situation in the present study. Therefore, research and extension expenditures are combined.

Taking the natural logarithm of the technology index T, equation (3) becomes:

$$(4)\ \ln T = \sum_{j=0}^{13} \gamma_j \bullet \ln R_{t-j} = \beta \bullet \sum_{j=0}^{13} \delta_j \bullet \ln R_{t-j} = \beta \bullet \ln S,$$

where δ_j is the weight associated with R_{t-j}, β is a parameter to be estimated, and $S = \prod_{j=0}^{13} R_{t-j}^{\delta_j}$.

Substituting equation (4) into (2), the translog production function to be estimated becomes:

$$(5)\ \ln Q_{kt} = \alpha_k + \alpha_T \bullet \beta \bullet \ln S_{kt} + \sum_{i=1}^{n} \alpha_i \bullet \ln X_{ikt} + \frac{1}{2} \bullet \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \bullet \ln X_{ikt} \bullet \ln X_{jkt} + \sum_{i=1}^{n} \gamma_{iT} \bullet \beta \bullet \ln X_{ikt} \bullet \ln S_{kt} + \frac{1}{2} \bullet \gamma_{TT} \bullet \beta^2 \bullet (\ln S_{kt})^2 + e_{kt}.$$

[2]A different estimation approach has been used when it is not efficient in terms of time or cost to increase sample size. In such cases, the approach taken has been to assume profit maximization in competitive product and factor markets and derive a set of semi-logarithmic equations. Parameters of the translog function can then be estimated from this set of equations (Berndt and Christensen). However, if the underlying technology is not translog, the system approach is subject to specification error and the single equation estimating method would perform better (Guilkey and Lovell).

[3]The ten production regions are: (1) Northeast, (2) Lake States, (3) Corn Belt, (4) Northern Plains, (5) Appalachian, (6) Southeast, (7) Delta States, (8) Southern Plains, (9) Mountain, and (10) Pacific as defined in *Farm Real Estate Market Developments* (USDA).

ESTIMATING PROCEDURES

Equation (5) is a time series cross-sectional model. Thus, it is appropriate to assume that serial correlation and contemporaneous correlation problems exist. Hence, the disturbance terms in a region and among regions are assumed to be serially and contemporaneously correlated, respectively.

The symmetry restrictions ($\gamma_{ij} = \gamma_{ji}$ and $\gamma_{iT} = \gamma_{Ti}$) are imposed in estimating the model. Parameters of equation (5) are estimated using a generalized least squares procedure which estimates a first-order serial correlation coefficient for the regions with significant serial correlation problems, and adjustments for serial correlation are made in these regions 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.

Equation (5) is estimated twice: first, all parameters are estimated for the translog model and secondly, all γ_{ij} and γ_{iT} parameters are assumed to be zero to estimate the Cobb-Douglas model. These restrictions on γ_{ij} and γ_{iT} are tested to see whether the Cobb-Douglas model is appropriate. The regression coefficients in the translog model, in particular, are difficult to interpret directly, so the estimated regression coefficients will be used to estimate elasticity of production of R & E expenditures, marginal products of R & E expenditures, and the internal rates of return for R & E.

The elasticity of production can be calculated from the estimated regression coefficient by taking the partial derivative of equation (5) relative to each explanatory variable. For example, the elasticity of production of S, which is represented by (E_s), can be calculated as:

$$(6)\ E_{s_{kt}} = \frac{\partial Q_{kt}}{\partial S_{kt}} \bullet \frac{S_{kt}}{Q_{kt}} = \frac{\partial \ln Q_{kt}}{\partial \ln S_{kt}}.$$

For the Cobb-Douglas production function, the regression coefficient is the elasticity of production. But for the translog production function, the estimated coefficients cannot be interpreted apart from input data and E_s is calculated as:

$$(7)\ E_{s_{kt}} = \frac{\partial \ln Q_{kt}}{\partial \ln S_{kt}} = \alpha_T \bullet \beta + \sum_{i=1}^{n} \gamma_{iT} \bullet \beta \bullet \ln X_{ikt} + \gamma_{TT} \bullet \beta^2 \bullet \ln S_{kt}.$$

Because the particular interest of this study is to quantify contributions of R & E on agricultural production, the elasticity of production of R & E (E_R) is derived from the estimated coefficients through equation (8):

$$\begin{aligned}(8)\ E_{R_{jk}} &= \frac{\partial Q_{jk}}{\partial R_{jk}} \bullet \frac{R_{jk}}{Q_{jk}} \\ &= \frac{\partial Q_{jk}}{\partial T_{jk}} \bullet \frac{\partial T_{jk}}{\partial R_{jk}} \bullet \frac{R_{jk}}{T_{jk}} \bullet \frac{T_{jk}}{Q_{jk}} \\ &= E_{T_{jk}} \bullet \gamma_{jk} \\ &= \frac{1}{\beta} \bullet E_{s_{jk}} \bullet \beta \bullet \delta_{jk} \\ &= E_{s_{jk}} \bullet \delta_j;\ j = t-13, t-12, ..., t;\ \text{and} \\ & \qquad k = 1, ..., 10.\end{aligned}$$

Then, the marginal products of R & E for each of the fourteen years are derived as follows:

$$(9)\ MP_{jk} = E_{R_{jk}} \bullet \frac{\bar{Q}_k}{\bar{R}_k},$$

where $\bar{Q}_k$ and $\bar{R}_k$ are the mean level of agricultural output and R & E expenditures in region k, respectively, with $\bar{Q}$ and $\bar{R}$ based on 1972 dollars. Total effects of R & E expenditures (TMP) can be obtained by aggregating MP over the lifetime of the investment; that is,

$$(10)\ TMP_k = \sum_j MP_{jk}.$$

Since the R & E expenditures in this study do not include the private sector research expenditures, the estimated TMP would tend to overestimate the marginal product for public sector R & E. However, it is generally concluded that the effects of public research, extension, and private research are about equal (Bredahl and Peterson). Since only two of the three categories were considered in this study, the calculated TMP's were reduced by one-third in order to account for the omitted private research component.

Since the returns are not forthcoming immediately, it is important to determine the rate of return associated with R & E investments. The internal rate of return (IRR) is calculated following equation (11) so that the lag structure is taken into account; that is,

$$(11)\ \sum_{i=0}^{n} \frac{MP_i}{(1 + IRR)^i} - 1 = 0.$$

DATA

The time period in this study covers the 1949-81 period for the ten production regions in the United States. Data on research and extension expenditures covered the 1936-81 period to account for the lag structure on these expenditures. Research and extension expenditures included only production-oriented expenditures, excluding such nonproduction-oriented activities as marketing research, human nutrition research, and 4-H extension programs. Data sources for these expenditures include *Budget of the United States Government; Combined Statement of Receipts, Expenditures and Balances of the United States Government* (United States Department of Treasury); *Funds for Research at State Agricultural Experiment Stations and Other State Institutions* (United States Department of Agriculture, Cooperative State Research Service); and *Annual Report of Cooperative Extension Work in Agriculture* (United States Department of Agriculture, Federal Extension Service). A detailed description of these data sources is given in Cline. Data for production-oriented research expenditures since 1972 were obtained from the annual issues of *Inventory of Agricultural Research* (United States Department of Agriculture Cooperative State Research Service) by summing the expenditures for production-oriented Research Program Areas (RPA's). Research and extension expenditures are all recorded in millions of dollars and deflated by the implicit deflator for government purchases of goods and services with 1972 as the base (United States Department of Commerce, *Survey of Current Business*).

Agricultural output and input data, including variable inputs, were obtained from *Farm Income Statistics* and *Economic Indicators of the Farm Sector* (United States Department of Agriculture). The value of land and buildings was derived from *Agricultural Statistics* (USDA). Agricultural output was the sum of farmer cash marketing[4], 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. The labor input was the total hours used for all farm work times the real farm wage rate per hour. Total hours used for all farm work were reported in *Economic Indicators of the Farm Sector*. The index of mechanical power and machinery power, which was reported in *Economic Indicators of the Farm Sector* was used for the capital variable. Expenditures for feed, livestock[5], seed, fertilizer, lime and miscellaneous were deflated with the index of prices paid for feed, livestock, seed, fertilizer, and all items in production, respectively. All price indices are based in 1972.

RESULTS

Empirical results using the translog production function are compared with results from the more traditional Cobb-Douglas production function, tables 1 and 2. The R^2's are high for both functions and most of the explanatory variables are significant. Among the conventional inputs, capital and intermediate inputs had the highest elasticities of production. For the Cobb-Douglas function, the elasticity of production was 0.48 for capital and 0.22 for

TABLE 1. ESTIMATED RESULTS OF THE TRANSLOG PRODUCTION FUNCTION FOR AGGREGATE U.S. AGRICULTURE, 1949-1981

Parameter	Estimate	t-value
Regional intercepts		
Northeast	.4945	.8011
Lake States	.5618	.9084
Corn Belt	.4780	.7730
Northern Plains	.5159	.8361
Appalachian	.5820	.9444
Southeast	.5323	.8624
Delta States	.5764	.9357
Southern Plains	.4911	.8012
Mountain	.6745	1.0976
Pacific	.6090	.9900
ln S (research and extension)	.0010[a]	3.8902
ln L (labor)	-1.7605[a]	-8.4326
ln C (capital)	.4281[a]	2.3583
ln A (land)	-1.2627[a]	-5.7830
ln F (intermediate inputs)	2.6013[a]	8.6395
(ln L)²	.2396[a]	7.7952
ln L · ln C	-.1124[a]	-2.4141
ln L · ln F	-.3004[a]	-6.997
ln L · ln A	.0758[a]	2.0871
ln L · ln S	.0003[a]	8.8199
(ln C)²	-.0084	-.4213
ln C · ln F	.4638[a]	7.9157
ln C · ln A	-.2953[a]	-7.0365
ln C · ln S	.0001[a]	4.4861
(ln A)²	.0882[a]	2.6393
ln A · ln F	-.0565	-.8384
ln A · ln S	.0002[a]	5.3431
(ln F)²	-.1231[a]	-2.6622
ln F · ln S	-.0004[a]	-7.7394
(ln S)²	-16×10^{-8}[a]	-6.3054
R^2	.9965	

[a]Significant at 1 percent significance level.

TABLE 2. ESTIMATED RESULTS OF THE COBB-DOUGLAS PRODUCTION FUNCTION FOR AGGREGATE U.S. AGRICULTURE, 1949-1981

Parameter	Estimate	t-value
Regional intercepts		
Northeast	.1149	.6475
Lake States	.0127	.0623
Corn Belt	.0263	.1342
Northern Plains	.0970	.5321
Appalachian	.0364	.1787
Southeast	.0102	.0497
Delta States	.0422	.2070
Southern Plains	-.0120	-.0572
Mountain	.1599	.9531
Pacific	.1259	.6355
ln S (research and extension)	.0002[a]	5.0000
ln L (labor)	.0776[a]	2.9608
ln C (capital)	.4785[a]	21.8833
ln A (land)	.0838[a]	3.6581
ln F (intermediate inputs)	.2235[a]	8.4917
R^2	.9954	

[a]Significant at 1 percent significance level.

[4]Cash marketings would cause problems of double counting, but intermediate products are included in intermediate inputs to mitigate the problem.

[5]Although it might be desirable to handle breeding livestock separately from other livestock, available data do not permit such separation between the capital and intermediate input variables.

TABLE 3. THE TOTAL MARGINAL PRODUCT (TMP) AND INTERNAL RATE OF RETURN (IRR) OF RESEARCH AND EXTENSION EXPENDITURES IN THE UNITED STATES AND 10 PRODUCTION REGIONS IN 1972 DOLLARS, 1949-81

Region	Translog			Cobb-Douglas[a]	
	E_s	TMP	IRR	TMP	IRR
		(Dollars)	(%)	(Dollars)	(%)
U. S. aggregate	.00018337	8.11	66	9.95	83
Northeast	.00016025	3.89	30	5.48	44
Lake States	.00017888	8.02	65	10.12	84
Corn Belt	.00006987	5.42	41	17.49	169
Northern Plains	.00022358	16.06	150	16.20	152
Appalachian	.00026846	9.05	75	7.60	62
Southeast	.00017513	5.07	40	6.53	53
Delta States	.00016400	5.17	41	7.12	58
Southern Plains	.00011394	7.23	59	14.10	126
Mountain	.00032333	12.45	108	8.68	71
Pacific	.00017283	7.08	57	9.24	76

[a]The numerical value of E_s, the elasticity of production for the technology variable, S, was .000225 for all regions with the Cobb-Douglas production function.

intermediate inputs. These estimates varied through time for the translog function, but its average elasticity of production over the period of analysis was 0.55 for capital and 0.38 for intermediate products. A comparison of translog and Cobb-Douglas elasticities of production for conventional inputs indicated that the translog gave larger estimates for capital and intermediate inputs and smaller estimates for labor and land.

The estimated TMP and IRR for the United States and 10 production regions are presented in Table 3. Using a translog production function, the TMP was $8.11 and the IRR was 66 percent for the United States as a whole, while the Cobb-Douglas estimates were $9.95 and 83 percent, respectively. In general, the Cobb-Douglas production function tends to have higher estimates of marginal products and internal rates of return, except for the Appalachian and Mountain regions. The difference in TMP and IRR among regions can be explained by two sources: elasticity of production of R & E expenditures and the ratio of value of agricultural output to R & E expenditures. For the Cobb-Douglas production function, the elasticity of production is constant and the regional difference in TMP and IRR is determined only by the magnitude of the ratio of value of agricultural output to R & E expenditures. For the translog production function, however, the elasticity of production of R & E expenditures is not the same for each region, which contributes to regional differences in TMP and IRR.

From the estimated translog production function, it is possible to test the Cobb-Douglas functional form hypothesis to determine if it is appropriate to use the Cobb-Douglas production function. The translog production function as reported in equation (2) becomes a Cobb-Douglas production function if all $\gamma_{ij} = \gamma_{TT} = \gamma_{iT} = 0$. These restrictions were rejected at a 1 percent significance level indicating that the Cobb-Douglas function was not an appropriate functional form to use for an aggregate production function for U.S. agriculture for the period of this study, 1949-1981.

A comparison of the results from the two models is an indication of the magnitude of bias resulting from use of the restrictive Cobb-Douglas production function. The largest bias of MP is for the Corn Belt region. Among the translog production function estimates, the Northern Plains and Mountain regions have the highest marginal productivity, reflecting relatively low levels of R & E investments relative to agricultural output. In contrast, the Northeast, Southeast, Delta and Corn Belt regions have the lowest marginal productivity (IRR between .30 and .41). Nevertheless, the internal rates of return for these four regions are still comparable with alternative public investments. Based on these estimates, it would appear that the agricultural R & E investment would compare favorably with alternative public or private investments (Ruttan).

CONCLUSIONS

The Cobb-Douglas function has traditionally been used in the production function approach for estimating returns to agricultural research and extension. From the more general model presented in this paper (the translog function), it was shown that the Cobb-Douglas formulation implicitly assumes certain restrictions on parameter estimates that appear untenable. In particular, no interaction among inputs is allowed in the Cobb-Douglas formulation.

The translog function, with its attractive approximating property and less maintained hypotheses, was employed in this study to estimate effects of agricultural research and extension expenditures on productivity. The use of the broad cross-sectional and time-series data base allows the translog function to be estimated directly and mitigates the multicollinearity problem that might have occurred in estimating a translog production function. Results from this analysis indicate that the Cobb-Douglas production function would be inappropriate to apply to the agricultural sector. In fact, application of the Cobb-Douglas production function would seriously bias the marginal productivity and rates of return on investment in agricultural research and extension. The estimated marginal product of research and extension for the United States using a translog production function was $8.11 and internal rate of return was 66 percent. Among the ten production regions, the marginal product ranges from $3.89 (IRR: 30 percent) in the Northeast to $16.06 (IRR: 150 percent) in the Northern Plains. Marginal products for most of the regions are in the range of $5 to $9. These results indicate that the returns to agricultural research and extension investment would compare favorably with alternative public investments.

These results have important implications for further research. Use of the Cobb-Douglas formulation is called into question in estimating agricultural production functions. Further use of the translog and other flexible form production function approaches appear warranted. A major disadvantage of estimating the translog function directly, as in this study, is that a large data base is needed to mitigate possible problems of multicollinearity. However, this problem can be overcome by estimating the production function indirectly. This alternative for estimating the parameters of the translog function is to assume profit maximization in factor and product markets, which is efficient if the underlying technology is translog and if the number of sample observations is not enough to estimate a single translog function.

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