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A COMPARISON OF PROCEDURES FOR ESTIMATING RETURNS TO RESEARCH USING PRODUCTION FUNCTIONS

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The production function approach has been one of the two main ex-post procedures used to estimate the rate of return to agricultural research. A critical part of estimating the marginal internal rate of return (MIRR) is the procedure adopted to spread the benefits of research through time. Past studies using this approach have given only brief consideration to this computational procedure. The objective in this study was to review the different computational procedures used and, then, using cross-section production function estimates for U.S. agriculture, determine whether the MIRR estimates are sensitive to the computational procedure used. The results from this comparison indicate a large range in the estimates. The implication, then, is that careful consideration should be given to the choice of computational procedure, both when undertaking such a study and when comparing the results of different studies.

Introduction

Determination of the rate of return to investment in agricultural research has received considerable attention during the last twenty years. The so-called 'production function approach' has become one of the popular methods used to estimate the marginal internal rate of return (MIRR) to agricultural research.¹ To date, in studies using this approach, emphasis has been placed on the estimation of the research production coefficient.² None, however, have given detailed consideration to the computational procedure used to find the MIRR once this coefficient has been estimated.

In this paper, the objective is to summarise the important aspects of the MIRR computation; to determine whether all studies adopting this approach have used the same procedure; and to determine whether MIRR estimates are likely to be comparable between studies if different computational procedures have been used.

A Review of Computational Procedures Used in Past Studies

The most common model used in the production function approach is given by:

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¹ The initial application of this approach was by Griliches (1964).

² The more important of these studies are Griliches (1964); Peterson (1967); Evenson (1968); Cline and Lu (1976); Bredahl and Peterson (1976); and Fishelson (1971).

$$(1) \quad Q = A \prod_{j=1}^m X_j^{\beta_j} \prod_{i=0}^n R_{t-i}^{\alpha_{t-i}} e^u,$$

where Q = the per farm value of agricultural output;
 A = a shift factor;
 X_j = the conventional inputs;
 R_{t-i} = the expenditures on research in years t to $t-n$;
 β_j = the production coefficients on the conventional inputs;
 α_{t-i} = the partial production coefficients of research; and
 u = the random error term.

Only recently have attempts been made to estimate individual α_{t-i} values (for example, Cline 1975). In earlier studies, only the total research production coefficient, that is:

$$\alpha = \prod_{i=0}^n \alpha_{t-i}$$

was estimated. In the majority of these studies a single research (and sometimes extension) variable, composed of the weighted average of two or more years expenditure levels, has been used (e.g. Griliches 1964; Peterson 1967; Evenson 1968). Others, however, have used the level of expenditure in a single year as the appropriate variable (e.g. Bredahl and Peterson 1976).

Once these parameter estimates have been found a two step procedure has then been used to find the MIRR. First the total, or set of partial, value marginal products (VMP) of research are found. These are found by multiplying the research production coefficients estimated in equation (1) by the average product of research. The second step involves determining the discount rate (MIRR) which equates the discounted flow of these benefits with the discounted research cost. In the rest of this section, the important aspects of these two steps will be looked at separately.

Calculation of the value marginal product of research

As outlined above, the actual calculation of the VMP of research is a simple procedure. As a result, there has not been much variation between previous studies in this part of the calculation. There are, however, a few differences which are potential sources of variation in the final MIRR estimates.

The most important potential source of variation is in the interpretation of the VMP resulting from differences in the units of measurement for the output and research variables. The output variable most frequently used in model estimation has been the value of output deflated to constant price levels at a particular point in time and/or between cross-section observations.³ On the other hand, two alternative units of measure have been used for the research variable. In some studies, such

³ The exceptions to this have been Evenson (1968) and Cline (1975) who used a productivity index as their dependent variable. When estimating the VMPs though, they have converted this index back to an equivalent value of output basis.

as Evenson (1968) and Cline (1975), research expenditure levels have been deflated to remove the influence of changes in the prices of research inputs, but Griliches (1964), Peterson (1967) and Fishelson (1971) have used current dollar values. The approach adopted in past studies for calculating the VMP has been to find the average product using the geometric means of the data used in the model estimation. While Davis (1979, p. 51) has shown that using deflated or undeflated research expenditure does not affect the coefficient estimates, it will affect the value and interpretation of the VMP. In addition, as shown below, it is inappropriate to use the value of output deflated by commodity price deflators in this calculation.

In production economics theory, a production function estimate, with output and all inputs measured in physical units, will give the VMP as the marginal product multiplied by the product price. When some of the variables are measured in dollar terms care is required in the interpretation of these measures. Consider the value of output variable used in research evaluation studies. If the commodity price deflators successfully eliminate the price effects from the data, then the marginal product will be close to a physical measure. To find the VMP it is then necessary to multiply this by the product price. In all studies, either aggregate output or groupings of commodities have been used. A single price, therefore, does not exist. The easiest procedure is to use the geometric mean of the original current dollar value of output. As pointed out above, previous studies (e.g. Griliches 1964; Bredahl and Peterson 1976) have used the geometric means of the deflated output values.

While the current dollar value of output is the appropriate measure to use in calculating the VMP, there is still a problem if these estimates are to be compared over time, since they will be affected by the general level of inflation. The issue, then, is whether it is desirable to make comparisons in real or current dollar values. If the former is desired, then the VMP should be deflated by an appropriate index reflecting the level of inflation. The marginal product of research, derived from undeflated research expenditure data, can be interpreted as the change in output for a current dollar increase in research expenditure. However, for the deflated data, it is the change for a constant unit input of research effort which is more useful for comparisons through time.

To summarise, the most appropriate geometric means to use in calculating the VMP are the current total value of output, deflated by an appropriate inflation indicator, and the research expenditure level, deflated by an appropriate index of research input prices. No past studies have used this. For example, Griliches (1964), Peterson (1967), Fishelson (1971) and Bredahl (1975) used the value of output deflated by commodity price indexes and undeflated research expenditures. Evenson (1968) used the same output measure but deflated research expenditure.

Another aspect of the VMP calculation which has been treated differently in past studies is the adjustment made to allow for the impact of private sector research. Two alternative arguments have been used. One is based on the premise that average product is over-estimated, while the other argues that the research production coefficient is biased upwards. Which argument is appropriate determines the hypothesised form of the specification of private sector research in the production function model. If it is assumed that private and public research expenditures are

proportional and should be added as a variable (at least in a Cob-Douglas function), then the biased average product argument is relevant. This is the approach taken by Griliches (1964), when he suggested that private research expenditure was about the same level as public research and therefore divided the VMP by two. On the other hand, if it is assumed that public and private research are positively correlated, but should be included as separate variables, then the production coefficient estimate will be biased upward. In this case, it is the coefficient which requires adjustment. This argument was used by Evenson (1968, pp. 71-2) to divide the coefficient for the U.S.A. by a factor of 1.22. The latter argument has the most conceptual appeal, although the size of the adjustment factor requires further investigation.

Calculation of the marginal internal rate of return

None of these previous researchers have used exactly the same procedure to calculate the MIRR from the VMP. The source of these differences lies in the method used to distribute the benefits of research over time. Further, in most cases, the procedure adopted has not been specified in a concise and consistent format. In the following, the different approaches are summarised and expressed in generalised and consistent notation.

A general procedure, reported in all studies, for finding the discount rate is that which satisfies discounted $VMP - 1 = 0$. The simplest procedure, used in the initial study by Griliches (1964), is to assume that all the benefits occur during one particular year. If this is the n th year after the expenditure date, then this becomes

$$(2) \quad [VMP/(1+r)^n] = 0,$$

which can be rearranged to give:

$$(3) \quad r = (VMP)^{1/n} - 1,$$

where $r = \text{MIRR}$.

Griliches made the unrealistic assumption that $n = 1$. A more reasonable assumption would be that n equals the mean lag of the distribution of the benefits. Equation (3) can be very useful for approximation purposes, because it is not necessary to use an iterative procedure to calculate the MIRR, as is the case with the other procedures.

Peterson (1967) assumed that the VMP is not attained for a period of n years after the expenditure, but then the same return continues into perpetuity. Under this assumption the MIRR is found from:

$$(4) \quad VMP \left[\sum_{i=n}^{\infty} 1/(1+r)^i \right] = 0$$

Clearly, if the n in equations (3) and (4) are the same, then the MIRR found from the latter equation will be considerably larger than from the former.

Most recent studies have made use of the conclusion of Evenson (1967), that the best representation of this lag is that of an inverted V.

There have been two slightly different uses made of this conclusion. The best way to illustrate this difference is with Figure 1. Evenson (1967) used a weighting procedure which assumed the VMP is distributed according to the histogram structure in Figure 1(a). On the other hand, Bredahl (1975) suggested that the benefits are spread as the area under the inverted V. This is the shaded area in Figure 1(b). Both procedures use the same basic equation to calculate the MIRR, that is:

$$(5) \quad VMP \left[\sum_{i=1}^n W_i / (1+r)^i \right] - 1 = 0$$

where W_i = the weight for period i ; and
 n = the total number of years over which past research has an impact on output and $S = n/2$ is called the mean lag.

The main distinction between the two procedures lies in the determination of the weights, W_i . Neither author developed a general specification of their alternative procedures. This has been done in the Appendix. For Evenson's procedure, the following weights were found:

$$(6) \quad W_i = i / \left[S + 2 \sum_{i=1}^{S-1} i \right],$$

for $i = 1$ to S ;

and

$$(7) \quad W_i = (n-i) / \left[S + 2 \sum_{i=1}^{S-1} i \right],$$

for $i = S+1$ to n .

On the other hand, as derived in the Appendix, Bredahl's procedure uses the weights:

$$(8) \quad W'_i = (2i-1)/2S^2,$$

for $i = 1$ to S ;

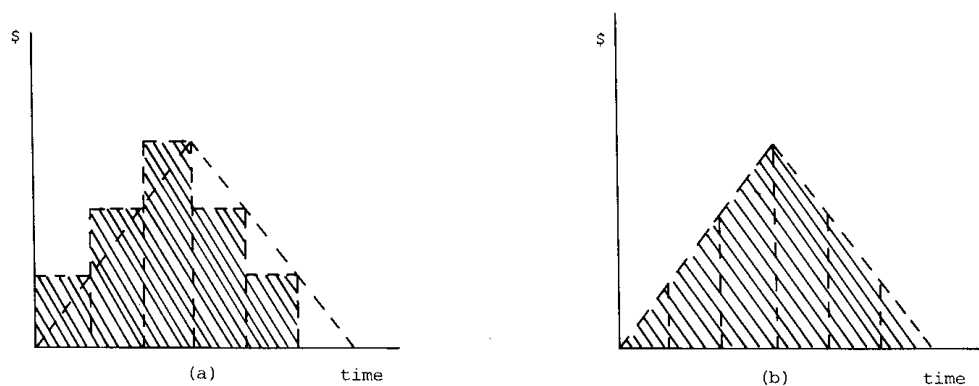


FIGURE 1—Alternative Distributions of the VMP of Research.

and

$$(9) \quad W_i = [2n - (2i - 1)]/2S^2, \\ \text{for } i = S + 1 \text{ to } n.$$

The easiest way to see the difference between the two is to notice that W_n is zero for Evenson's procedure but not Bredahl's. The result is that more of the benefits of research are assumed to accrue in earlier periods using Evenson's procedure.

All of the above procedures have used an estimate of the total production coefficient. More recently, studies have estimated the partial coefficients, thus providing scope for using slightly different MIRR estimation procedures. Cline (1975) estimated these partial coefficients and, although he estimated a productivity function, he found the VMP as:

$$(10) \quad VMP = \sum_{i=1}^n \alpha_i \bar{Q} / \bar{R},$$

where \bar{Q} = the average value of output over the time period of interest; and
 \bar{R} = the average research expenditure over the same period.

With this estimate he then used an equation similar to equation (5) to find the MIRR, except his weights were found as:

$$(11) \quad \bar{W}_i = \alpha_i / \sum_{i=1}^n \alpha_i.$$

The critical aspect of Cline's procedure is determining the length of the period for which the averages for output and research are found.

All of the above procedures should be related to the use that is to be made of the estimated MIRR. Two possibilities exist. The first is that decision makers may wish to know the impact of all previous research on output in a particular year. It is an approximation of this that has been estimated in most past studies. The second alternative suggests that it is desirable to know the impact of research expenditure of a particular year on output in all subsequent years. The latter is probably the most relevant for decision makers considering the appropriate level of current research expenditure.

The appropriate estimation formulae are, for the first possibility:

$$(12) \quad \sum_{i=1}^n [\alpha_i Q_n / R_i (1 + r)^i] - 1 = 0;$$

and for the second possibility:

$$(13) \quad \sum_{i=1}^n [\alpha_i Q_i / R_i (1 + r)^i] - 1 = 0;$$

It is seen that the basic difference is that in equation (12) the level of research expenditure changes for a given output level, while in equation (13) the opposite applies.

A Comparison of Alternative Computational Procedures

On the basis of past studies reviewed in the previous section it can be concluded that there is considerable variation in the computational procedures adopted for calculating the MIRR to research expenditure. Conceptually, the most appropriate estimate is calculated as the change in output over a series of years resulting from a change in research expenditure in a particular year. This is expressed in equation (13). Also, especially if comparisons are to be made over time, the appropriate output measure to use is the current commodity price value deflated by a general level of inflation index, and the appropriate research expenditure level is the current dollar value deflated by an index reflecting changes in research input costs. No past study has used this model. This has been due partly to rather demanding data requirements. More important, however, is the fact that no two of these studies have used exactly the same computational procedure and, therefore, none of the MIRR estimates are strictly comparable.

During recent years it has become common to make use of summary tables of rates of return to research estimates.⁴ The production function approach estimates make up approximately half of those summarised. It is important, then, to assess the sensitivity of the MIRR estimates to the computational procedure adopted, as this may affect their comparability.

In this section, comparisons are made using results from an aggregate U.S. agriculture study by Davis (1979).⁵ Davis estimated two pooled cross-section/time series Cobb-Douglas production functions for the five year census periods 1949 to 1959 and 1964 to 1974. The cross-section units of observation were the 40 major agricultural States in the U.S.A. The model specification and variable definitions were based on those used in Griliches (1964).

The partial and total research production coefficients (production elasticities) used are given in Table 1. These were taken from Davis (1979, p. 107) and were found by using a constrained second-order polynomial lag model, assuming a 14-year lag. In this case, the total production coefficients of 0.068 and 0.034 are the sum of the respective partial coefficients. Davis (1980) has shown that the sum of these partial coefficients is not significantly different from the total production coefficients estimated using the specifications commonly employed in earlier studies. It is, therefore, consistent to use the estimates presented in Table 1 to give MIRR estimates using all of the computational procedures summarised in the previous section.

In addition to the eight alternative computational procedures, results are compared for the six possible interpretations of the VMP. These involve deflated and undeflated research expenditure and three measures of output. Research expenditure was deflated by an index of professors' salaries at agricultural experiment stations (see Davis 1979, p. 138). The three output measures include the current dollar value, and output deflated by indexes of commodity prices and the wholesale price index. In Table 2, the MIRR estimates for these cross classifications for the years 1954 and 1964 are presented.

Inspection of Table 2 reveals considerable variability in the rate of

⁴ A recent version of this type of table is presented by Ruttan (1978).

⁵ A summary of this study is also available in Davis and Peterson (1980).

TABLE 1
*Partial Research Production Coefficients for Pooled
 Production Functions*

Time period	1949-1959	1964-1974
t	.001699	.000849
t-1	.003154	.001576
t-2	.004368	.002182
t-3	.005339	.002667
t-4	.006067	.003031
t-5	.006552	.003274
t-6	.006795	.003395
t-7	.006795	.003274
t-8	.006552	.003031
t-9	.006067	.002667
t-10	.005339	.002182
t-11	.004368	.002182
t-12	.003154	.001576
t-13	.001699	.000849
Total	.068	.034

return estimates found. Considering first, the sensitivity to computational procedures only, it is seen that, for 1954, there is a range of 63.0 to 153.7 per cent for current dollar research and 48.2 to 82.9 per cent for deflated research expenditure. Similar ranges for 1964 are 31.4 to 52.9 per cent and 28.1 to 49.9 per cent, with some concentration around the middle of these ranges. Second, if the interpretation of the VMP, as well as the computational procedure is varied, the range in the estimates increases to 45.4-153.7 per cent for 1954 and 27.1-53.5 per cent for 1964. The differences are obviously substantial enough to warrant caution when making comparisons between studies and over time.

In summary, the use of current or deflated research expenditure does change the absolute levels of the MIRR estimates. If MIRR estimates are compared over time, the form of this expenditure will become an important factor. For the analysis in Table 2, the choice of the appropriate measure of output is less important. However, this aspect of the interpretation should not be ignored, especially in periods of rapidly changing prices.

Decision makers are usually more interested in the rate of change in rates of return over time rather than their absolute values. In Table 3, the percentage decrease in the MIRRs between 1954 and 1964 are presented. It is seen that, while some variability still exists between the computational procedures, these differences are not as great.

As expected, the decrease is smaller for the deflated research expenditure situation. The implication is, with the possible exception of equations (3) and (4), that the choice of computational procedure is not as critical for comparisons through time, as long as the same procedure is used throughout.

Conclusion

A review of the literature reveals that the interpretation of the VMP, and the subsequent choice of the MIRR computational procedure, has

TABLE 3
Percentage Decrease in MIRR Estimates for the U.S.A. between 1954 and 1964

	Current dollar research			Constant dollar research		
	Output (deflated by commodity prices)	Output (current dollar)	Output (deflated by wholesale price index)	Output (deflated by commodity prices)	Output (current dollar)	Output (deflated by wholesale price index)
Equation (3) $n = 7$	47.4	49.3	50.2	38.1	40.3	41.7
Equation (4) $n = 7$ (30 yr. planning horizon)	33.5	34.8	35.9	24.4	25.6	27.3
Evenson's equations (6 and 7)	62.3	63.8	65.6	48.2	50.5	52.7
Bredahl's equations (8 and 9)	59.5	60.9	62.5	46.4	48.4	50.6
Cline's equations (10 and 11) (Previous 10 year average)	n.a.	63.5	65.6	n.a.	53.5	55.9
Increase in current year						
Output equation (12)	n.a.	62.9	64.9	n.a.	50.8	53.3
Cline's equations (10 and 11) (Future 10 year average)	n.a.	60.7	65.6	n.a.	37.8	45.5
Returns to current year						
Research equation (13)	n.a.	60.4	64.7	n.a.	43.6	49.7

been a relatively neglected area of the production function approach used to evaluate agricultural research. Further, a range of alternative computational procedures have been used in past studies.

The main conclusion to be drawn from the empirical work is that the MIRR estimate is sensitive to the calculation of the VMP, and to the procedure used to compute the MIRR from the VMP. It was concluded that the more appealing concept was the return to research in a particular year (equation 13) but the appropriate data may not be available. However, it was shown to be most important to ensure that, in making comparisons over time or between studies, the same computational procedure has been used. Finally, in future studies the computational procedure used should be clearly specified. Also, it is important to present the basic data used to calculate the MIRR, so that subsequent researchers can use alternative computational procedures if comparisons are desired.

APPENDIX

The boundaries of the inverted V in Figure 1 can be represented by, for the first half:

$$(A.1) \quad y = ax,$$

and for the second half:

$$(A.2) \quad y = b - ax.$$

If n is the length of the lag, and therefore, $\bar{S} = n/2$ is the mean lag, then for equation (A.2), when $y = 0$, $x = n$, and by substituting and rearranging, it is seen that $b = an$. With this result, equation (A.2) becomes:

$$(A.3) \quad y = a(n - x).$$

With this information, it is possible to calculate a general form for both Evenson's and Bredahl's weights.

Evenson's approach

The area of each of the rectangles in Figure 1(a) is given by:

$$(A.4) \quad A_i = ai,$$

for $i = 1$ to S ;

and

$$(A.5) \quad A_i = a(n - i),$$

for $i = S$ to n

The total area, which equals the VMP, is then given by:

$$\begin{aligned} TA &= \sum_{i=1}^S ai + \sum_{i=S+1}^n a(n - i) \\ &= a \left[S + \sum_{i=1}^{S-1} i + \sum_{i=S+1}^n (n - i) \right]. \end{aligned}$$

Since it can be shown that:

$$\sum_{i=S+1}^n (n - i) = \sum_{i=1}^{S-1} i,$$

the total area becomes:

$$(A.6) \quad TA = a \left[S + 2 \sum_{i=1}^{S-1} i \right].$$

From equations (A.4), (A.5) and (A.6), the general form of the weights are found as $W_i = A_i / TA$. For $i = 1$ to S :

$$(A.7) \quad W_i = i / \left[S + 2 \sum_{i=1}^{S-1} i \right],$$

and

$$(A.8) \quad W_i = (n - i) / \left[S + 2 \sum_{i=1}^{S-1} i \right],$$

for $i = S + 1$ to n .

Bredahl's approach

The area for each time period for $i = 1$ to S can be represented by:

$$\begin{aligned} A'_i &= \int_{i-1}^i ax \, dx \\ &= [(a/2)x^2]_{i-1}^i \\ (A.9) \quad &= a/2[2i - 1]. \end{aligned}$$

For each time period for $i = S + 1$ to n this area is given by:

$$\begin{aligned} A'_i &= \int_{i-1}^i a(n-x)dx \\ &= [anx - (a/2)x^2]_{i-1}^i \\ (A.10) \quad &= a/2[2n - (2i - 1)] \end{aligned}$$

Finally, the total area under the inverted V is twice the area from $i = 0$ to S . That is:

$$\begin{aligned} TA &= 2 \int_0^S ax \, dx \\ (A.11) \quad &= 2((a/2)S^2) \end{aligned}$$

From equations (A.9), (A.10) and (A.11), the general form of the weights are found as $W'_i = A'_i / TA'$. For $i = 1$ to S :

$$(A.12) \quad W'_i = (2i - 1)/2S^2,$$

and

$$(A.13) \quad W'_i = [2n - (2i - 1)]/2S^2$$

for $i = S + 1$ to n .

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