# Evaluating Agricultural Research and Productivity

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# ECONOMIC EVALUATION OF FORESTRY RESEARCH: SYNTHESIS AND METHODOLOGY

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## INTRODUCTION

Interest in the economic impacts of research and development (R&D) among forest economists is of relatively recent vintage when compared with the long history of such inquiries in agricultural economics. In contrast to the literature in agricultural economics, which can be traced to the seminal works of Schultz (1953) and Griliches (1958), such work in forest economics was not of widespread interest until 1979 when the USDA Forest Service responded to the Forest and Rangeland Renewable Resources Planning Act of 1974 by initiating an examination of policy concerning public support for R&D (Callaham, 1981). In 1980 the Forest Service began a national program to develop methods for the economic evaluation of R&D in forest product technologies under the initial direction of Allen Lundgren at the North Central Forest Experiment Station.[1]

The research program established by the North Central Forest Experiment Station had five broad components ranging from the identification of the users of forestry research evaluation and their needs to the development of methods for evaluating that research (Lundgren, 1983). The bulk of the work which has been completed may be classified, following Bengston (1986), as impact evaluations and process evaluations. Impact evaluations examine effects of R&D on the economy, and are represented by estimates of the increase of producer and consumer surplus due to R&D, estimates of the marginal productivity of R&D expenditures, and studies of the effect of R&D on employment, income and income distribution, the balance of trade, the environment, and market structure. Process evaluations examine the research process itself within the economic organization in order to determine how decisions are made and R&D is carried out. Such studies focus on how the agency or firm selects, plans, monitors, and evaluates projects. The goal of this kind of evaluation is to improve the research decision-making.

A broad overview of many of the impact and process evaluation studies in forestry may be found in Bengston (1986). This paper concentrates instead of two types of impact evaluation approaches which have been adopted and modified for forestry R&D evaluation from agricultural economics. Results of such studies in forest economics are presented in the next section. Following that section, methodologies are discussed. While the theoretical underpinnings of these methodologies are well known to agricultural economists, details differ to a lesser or greater extent in the forestry studies, and may be of interest. The methodology developed in Seldon (1987) and Seldon and Newman (1987) is described in detail.

## EVALUATION OF RETURNS TO RESEARCH IN FORESTRY ECONOMICS

Two methods which have been adopted for measuring returns to research expenditures in forest economics are quite familiar to agricultural economists.[2] Following Norton and Davis (1981), the first method is often referred to as the consumer and producer surplus (or CS) approach, and measures increases to these surpluses net of research costs. This method is most often used to calculate an internal rate of return (IRR) to R&D expenditures. The economic benefits calculated by this method are presumed to be generated by the shifting of the supply curve or reductions in marginal cost caused by (process) R&D. The second method is the production function (PF) approach which allows the calculation of the value of the marginal product of research expenditures and is sometimes used to calculate a <u>marginal</u> internal rate of return (MIRR) to R&D expenditures.

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Due to the deficiency of detailed data, the CS method is the most commonly applied in forestry studies. The techniques for measuring benefits and costs in different studies vary according to the availability of data. A somewhat different approach which ties the CS and PF approaches together has been developed by Seldon (1985 and 1987) and is currently being applied to several forest product industries in on-going research at Duke University.[3]

Details of some CS and PF studies are discussed in the next section. First, however, the results of forestry studies completed to date are presented in Table 1. Most of the CS

Table 1. Estimated Returns to Forestry Research

| Product | Author | IRR Calculated for: | IRR Range (Percent) | MIRR Range (Percent) |
|---|---|---|---|---|
| Structural Particleboard | Bengston (1984) | Consumer Surplus | 18-22 | -------- |
| Lumber, Plywood, Pulp & Paper | Haygreen et al. (1986) | Consumer Surplus | 14-36 | -------- |
| Timber (Containerized Seedlings) | Westgate (1986) | Consumer Surplus | 37-111 | -------- |
| Aggregate Lumber & Wood | Bengston (1985) | Consumer Surplus | 34-40 | -------- |
| Timber (Forest Nutrition) | Bare and Loveless (1985) | Consumer Surplus | 9-12 | -------- |
| Softwood Plywood | Seldon (1987) | Consumer Surplus | 244-440 | -------- |
| -------- | -------- | Total Economic Benefit | 375-661 | -------- |
| Softwood Plywood | Seldon and Newman (1987) | -------- | -------- | 236-438 |
| Preserved Wood | Brunner and Strauss (1986) | Total Economic Benefit | 73 | -------- |
| Southern Softwood Stumpage | Newman (1986) | Total Economic Benefit | 0-7 | -------- |

Brunner and Strauss (1986) do not calculate the IRR, but rather report the net present values of the 1950-1980 research program in wood preserving. The estimate presented here is a preliminary estimate of the IRR from their data and is reported in Hyde (1986).

Chang (1986) considers returns to growth and yield models for loblolly pine. He does not report an IRR, but does calculate a benefit/cost ratio of 16/1.

studies have calculated the IRR from consumer surplus only, but two of the studies also calculate the IRR from total economic benefit (the sum of consumer surplus and producer surplus). The calculation of producer surplus is valid only where the market may be assumed competitive or contestable, but this seems to be true for forestry markets.[4] Most of the calculated returns are within the neighborhood of returns calculated in agricultural studies (see Evenson et al. 1979, Ruttan 1980, or Evenson 1982) with the exception of the results for softwood plywood. The softwood plywood study uses a rather different approach which will be examined in more detail in a later section. For now it suffices to note that the same approach is being used for the wood preserving industry, and preliminary results of that study are close to the estimates for other forest (and agricultural) products.

Some Details of Selected Studies

In this section, the methodologies employed by Bengston (1983 and 1984), Seldon (1987) and Seldon and Newman (1987) are discussed. The approach used by Bengston is similar in many respects to previous CS studies, and is easily understood by the reader familiar with the literature. Bengston's analysis is representative of many of the forestry R&D studies. The method developed by Seldon will be introduced in this section in order to compare some of its aspects with Bengston's approach, but details are reserved for the next section. This method is used in Brunner and Strauss (1986) and is intended for use in further studies at Duke University's Center for Resource and Environmental Policy Research.

The first CS study completed in forestry economics was an evaluation of innovations which led to the development of structural particleboard (Bengston 1983 and 1984). While structural particleboard was a new product, Bengston treats the innovation as a new process which lowered the equilibrium price of sheathing material, since structural particleboard substitutes for softwood plywood in this capacity. The supply curve before the innovation may be conceptualized, then, as the supply curve for softwood plywood, while the supply curve after the innovation is properly considered to be the supply curve for structural particleboard. Bengston then applies an index number version of the CS method to calculate benefits in terms of consumer surplus, using previous estimates of the price elasticity of demand for softwood plywood as a proxy for the structural particleboard elasticity and assuming that the supply curves in both cases are perfectly elastic as in Griliches (1958).[5] Bengston forecasts future quantities of structural particleboard to the year 2000 using logistic growth curves. For any period t, then, the increase in consumer surplus is

$$\Delta CS_t = (P_t^{pw} - P_t^{pb})\, Q_t^{pb}\, (1 - k_t n/2)$$

where $\Delta CS_t$ = the change in consumer surplus

$P_t^{pw}$ = the price of plywood sheathing

$P_t^{pb}$ = the price of structural particleboard

$Q_t^{pb}$ = the quantity of structural particleboard consumed

$n$ = the price elasticity of demand for softwood plywood (used as proxy for the elasticity of structural particleboard)

$k_t = (P_t^{pw} - P_t^{pb}) / P_t^{pw}$

all at time t. This follows the formula given in Griliches (1958, p. 422) which is also reported in Norton and Davis (1981, p. 686).

To overcome data availability problems, Bengston devises a method to estimate costs which is subsequently used in Westgate (1986). For public sector expenditures, Bengston uses a count of screened publications to estimate government scientist years and multiplies this by an estimate of the cost of a scientist year. The cost series is developed using an academic R&D price index series (Sonka and Padberg, 1979) and Callaham's (1981, p. 26) estimate of the cost per scientist year to the Forest Service in 1977. Private cost estimates were obtained from industry specialists. Then these two costs are summed. Bengston calculates the cost of

continuing research to the year 2000 under the assumption that research will remain at its estimated 1981 level in terms of scientist years, but that the cost of a scientist year will increase at a real rate of 4.1 percent annually (the average annual increase in research costs between 1947 and 1979 in Sonka and Padberg (1979)). The IRR to structural particleboard in terms of consumer surplus is calculated to be between 18 to 22 percent under various assumptions imposed to check sensitivity of the estimate.

The method used by Bengston has appeal due to its simplicity and modest data requirements. The same cannot be said about the alternative approach used in Seldon (1987), Seldon and Newman (1987), and Brunner and Strauss (1986). The latter method, however, ties the CS and PF approaches together, and rather than assuming that all measurable benefits are due to R&D, this method statistically estimates the output elasticity of R&D expenditures in order to control for economic benefits due to factors other than R&D. In this section the approach is introduced and the more obvious comparisons are made with the method used by Bengston. Further justification for and explanation of the approach is reserved for the next section.

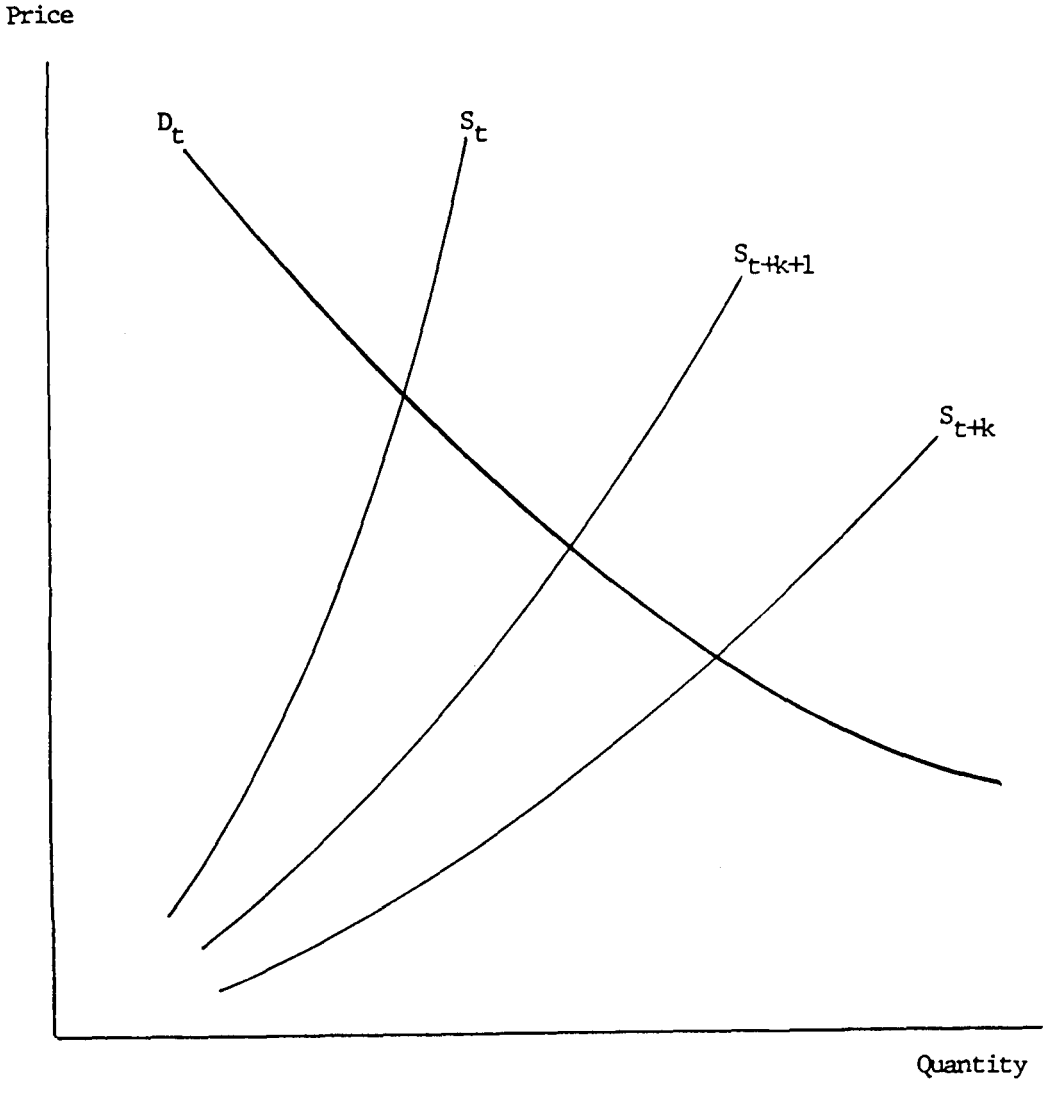
The studies by Seldon (1987), Seldon and Newman (1987), and Brunner and Strauss (1986) estimate the returns to public R&D only; the effects of privately initiated R&D are statistically controlled in a manner to be made clear in the next section. The approach is to specify a production function for the industry which includes research effort as a factor of production and which has a specific functional form, solve the profit maximization problem, and then derive the supply curve. This supply curve is then estimated simultaneously with a demand curve. This endogenously generates estimates of price elasticities of supply and demand so that the researcher does not have to rely on existing estimates which may be biased through the omission of research inputs. Since the production function includes research effort as a factor of production, the output elasticity of research falls through into the supply function as a shift parameter. The estimation of returns to research then follows.

The measurement of returns to consumer surplus and total economic benefit in the method is conceptually straightforward and is similar to the estimation of the effects of an exogenous shock in any stable system. For a given period t, one has observations of price and quantity and estimates of price elasticities of supply and demand and the output elasticity of research. Suppose, for instance, that the price and quantity observations and price elasticity estimates give rise to demand curve $D_t$ and supply curve $S_t$ in Figure 1. Suppose further that R&D conducted today begins to impact production k periods in the future (since it is unlikely that current R&D can be applied immediately). Given the research effort observed during period t and the output elasticity for that research at time t+k, the supply curve for period t+k can be constructed as $S_{t+k}$ in Figure 1. Note that this is the supply curve which would be expected in period t+k given the research effort in period t, ceteris paribus. The returns to research are then easily calculated mathematically.

The impact of R&D conducted at time t does not end in period t+k in general, but usually carries over into the future. The lag structure of the production function and econometric estimation of the supply and demand curve will suggest an output elasticity of research conducted in period t for supply in period t+k+1. Thus the supply curve for period t+k+1 may be constructed as, for example, $S_{t+k+1}$ in Figure 1, and the returns in period t+k+1 for research conducted in period t may be calculated, ceteris paribus. As pictured here, the benefits of R&D are depreciating as new research replaces the old. In subsequent periods, R&D effects will continue to depreciate with subsequent supply curves approaching $S_t$ until the difference is arbitrarily small and further benefits from R&D in period t can be ignored. Benefits are similarly estimated for all periods under consideration. Note that the estimation procedure is conservative since it does not consider any depreciation in the initial supply function over time.

The costs for public R&D in Seldon (1987), Seldon and Newman (1987), and in Brunner and Strauss (1986) are estimated by multiplying estimates of government scientist time (recorded in U.S. Forest Products Laboratory attainment reports) by an estimate of the cost of that time constructed in a manner similar to Bengston (1983 and 1984). Private implementation costs of publicly funded R&D are estimated for particular projects where data exist to obtain an estimate of the ratio of private expenditures to public expenditures necessary to

Figure 1. Future Returns To Research Conducted At Time t.



operationalize the public research.[6] Private implementation costs are then calculated from this ratio and estimates of public costs, and the private and public costs are then summed.[7]

The two approaches described in this section differ in the way returns to research are estimated. The first approach considers all measurable benefits caused by an outward shift of the supply curve to be the result of R&D. Since all residual benefits are attributed to R&D, one may call this a "residual" approach. The second approach tries to measure the output elasticity of R&D while controlling for other effects which may cause the supply curve to shift. Hence this approach may be called a "nonresidual" approach. This approach is a straightforward extension of the PF approach which is nonresidual in nature. The details are provided in the following section.

The Nonresidual Approach

The approach developed by Seldon is to specify a functional form for the industry production function and to derive the supply equation. Griliches (1979, pp. 95-6) suggests that the Cobb-Douglas form is useful in PF studies since the interactions among inputs are not of particular interest.[8] As Griliches (1979, p. 96) points out, a more general form would require observations with very different combinations of factors of production, but in many cases of interest there have not been radical changes in factor combinations.

The most general Cobb-Douglas form is

$$Q_t = Ae^{\theta t} L_t^{\alpha_1} K_t^{\alpha_2} Z_t \tag{1}$$

where $t$ = time
$Q_t$ = quantity produced
$A$ = constant
$e$ = base of natural logarithms
$L_t$ = labor services
$K_t$ = capital services
$Z_t$ = index of technology

For expositional ease, let $A = 1$ and $\theta = 0$, so

$$Q_t = L_t^{\alpha_1} K_t^{\alpha_2} Z_t.^{9} \tag{2}$$

The index of technology is a function of past R&D. The particular functional form which is used in any study depends on the particular market under consideration. In agricultural markets, the inverted V provides a close fit (Evenson, 1967). In manufacturing industries it is common to assume that, after the initial period of impact, the effect of R&D monotonically decreases.[10] For reasons discussed elsewhere (Seldon, 1985 and 1987) that assumption is adopted here. The particular functional form is

$$Z_t = \prod_{i=i_0}^{\infty} (S_{t-i}^{\eta} G_{t-i-j_0}^{\mu})^{\lambda^{i-i_0}} \quad ; \quad i_0>0,\ j_0 \geq 0 \tag{3}$$

where $S_t$ = private R&D expenditures
$G_t$ = government R&D effort.

These lags suggest that R&D results are not used immediately and that publically funded R&D may be subject to lengthier lags than private R&D.[11]

It is assumed that firms (and hence the industry) maximize cash flow each period and finance their R&D from the cash flow (Kamien and Schwartz, 1982, pp. 28-9). Thus the industry solves the problem

$$\max_{L,K} \Phi_t = P_t Q_t - W_t L_t - R_t K_t$$

subject to equations (2) and (3) where

$\Phi_t$ = cash flow
$P_t$ = real price per unit of output
$W_t$ = real hourly wage
$R_t$ = real user cost of capital

$S_t$ is <u>not</u> a control variable for this problem since current R&D expenditures raises profit in the <u>future</u>. The industry will fund current R&D ($S_t$) from this cash flow.[12]

Setting the first derivatives equal to zero and solving the two equations simultaneously yields

$$L^* = \alpha_1^{\gamma(1-\alpha_2)} \alpha_2^{\gamma\alpha_2} (PZ)^{\gamma} R^{-\gamma\alpha_2} W^{-\gamma(1-\alpha_2)} \tag{5}$$

and $$K^* = \alpha_1^{\gamma\alpha_1} \alpha_2^{\gamma(1-\alpha_1)} (PZ)^{\gamma} R^{-\gamma(1-\alpha_1)} W^{-\gamma\alpha_1} \tag{6}$$

where $$\gamma = (1-\alpha_1 - \alpha_2)^{-1}. \tag{7}$$

Asterisks indicate optimal levels, and time subscripts have been suppressed for convenience.

The profit each period after funding R&D expenditure is

$$\Pi_t = P_t Q_t^* - W_t L_t^* - R_t K_t^* - S_t \tag{8}$$

where $Q_t^*$ is given by equation (2) subject to equations (5), (6), and (7). It has often been noted and empirically supported that firms (and the industry aggregates) spend a stable fraction of total revenue on research.[13] Let f be the fraction, then

$$S_t = fP_t Q_t. \tag{9}$$

Then substituting equations (2), (3), (5), (6), (7) and (9) into (8), equating (8) to zero, and rearranging terms yields the supply equation

$$Q_t = (1-f)^{-1} AP_t^{\gamma(\alpha_1+\alpha_2)} W_t^{-\gamma\alpha_1} R_t^{-\gamma\alpha_2} \prod_{i=i_0}^{\infty} (S_{t-i}^{\gamma\eta\lambda^{i-i_0}} G_{t-i-j_0}^{\gamma\mu\lambda^{i-i_0}}) \tag{10}$$

where $$A = \alpha_1^{\gamma\alpha_1} \alpha_2^{\gamma(1-\alpha_1)} + \alpha_1^{\gamma(1-\alpha_2)} \alpha_2^{\gamma\alpha_2} \tag{11}$$

Taking the log of (10) and subtracting $\lambda \ln Q_{t-1}$ yields the Koyck transformation which is free of the infinite lag:

$$q_t = (1-\lambda) \ln A + \gamma(\alpha_1 + \alpha_2)(p_t - \lambda p_{t-1}) - \gamma\alpha_1(w_t - \lambda w_{t-1})$$

$$- \gamma\alpha_2(r_t - \lambda r_{t-1}) + \{(\lambda-1) \ln(1-f)\} + \gamma\eta s_{t-i_0} + \gamma\mu g_{t-i_0-j_0} + \lambda q_{t-1} \qquad (12)$$

where capitalized Roman letters have been replaced by their lower cases to represent logarithms, and $\gamma$ and A are defined by (7) and (11), respectively. The constant term in brackets is extremely small for reasonable estimates of f and $\lambda$, and may be excluded. Also $\ln(P_{t-i_0}Q_{t-i_0})$ can act as a proxy for $s_{t-i_0}$.

A demand function is specified next. In practice, a log linear demand function has been employed:

$$q_t = \underline{\beta}\underline{x} + \beta_1 p_t \qquad (13)$$

where $\underline{x}$ is a vector of demand shifters and $\underline{\beta}$ is a vector of coefficients. The supply and demand system is then estimated simultaneously using nonlinear methods.

Once this estimation is completed, the calculation of the VMP of government research is straightforward and similar to Griliches (1964): divide the (geometric) mean value of the output of the industry (in base year prices) by the geometric mean of public expenditures (also in base year prices) and multiply this by $\mu$. Since the impact is not realized until $i_0 + j_0$ periods later, the value should be discounted:

$$VMP_{GM} = \mu(PQ)_{GM} / (1-\rho)^{i_0 + j_0} E_{GM}$$

where E is public R&D expenditures (or, where appropriate, the sum of public expenditures and associated private implementation costs), GM signifies the geometric mean and $\rho$ is a discount rate. The MIRR is then calculated following Davis (1981): the MIRR is the value of $\rho$ such that[14]

$$VMP_{GM} \sum_{i=i_0+j_0}^{\infty} [\lambda^i/(1+\rho)^i]$$

$$= VMP_{GM} \{[(1+\rho)/(1+\rho-\lambda)] - \sum_{j=0}^{i_0+j_0-1} (\lambda/(1+\rho))^j\} = 1$$

The calculations of changes in consumer surplus and total economic benefit are more complex. Let $a_1$ and $a_2$ be the price elasticity of supply and R&D elasticity of supply respectively; that is,

$$a_1 = \gamma(\alpha_1 + \alpha_2)$$

$$a_2 = \gamma\mu.$$

Research today begins to impact supply in period $t+i_0+j_0$. Given the conditions and technology at time t, one would expect to observe the following future supply equations:

$$q_{t+i_0+j_0} = F_t^s + a_1 p_{t+i_0+j_0} + a_2 g_t$$

$$q_{t+i_0+j_0+1} = F_t^s + a_1 p_{t+i_0+j_0+1} + \lambda a_2 g_t$$

$$\vdots$$

$$q_{t+i_0+j_0+k} = F_t^s + a_1 p_{t+i_0+j_0+k} + \lambda^k a_2 g_t$$

$$\vdots$$

where $F_t^s$ is the intercept of the supply curve in period t, so that in general

$$Q_{t+i_0+j_0+k} = A_t^s G^{\lambda^k a_2} P_{t+i_0+j_0+k} \quad ; \; k = 0,1,2,\ldots \tag{14}$$

where $A_t^s$ is the antilogarithm of $F_t^s$. Similarly, the expected future demand curve would be

$$Q_{t+i_0+j_0+k} = A_t^d P_{t+i_0+j_0+k}^{-\beta_1} \quad ; \; k = 0,1,2,\ldots \tag{15}$$

Equating (14) and (15), equilibrium future prices are

$$P^e_{t+i_0+j_0+k} = (A_t^d/A_t^s)^{\delta} \; G^{-a_2\delta\lambda^k} = P_t G_t^{-a_2\delta\lambda^k}$$

where $\delta = (\beta_1 + a_1)^{-1}$. The last inequality results from solving for the price at time t from the original supply and demand equations:

$$Q_t = A_t^s \; P_t^{a_1} \tag{16}$$

and $$Q_t = A_t^d \; P_t^{-\beta_1} \tag{17}$$

The change in consumer surplus in time period $t+i_0+j_0+k$ due to government R&D at time t is

$$\int_{P^e_{t+i_0+j_0+k}}^{P^t} A^d_t P_t^{-\beta_1} \, dP = A^d_t (1-\beta_1)^{-1} (1-G^{\xi\lambda^k}) P_t^{1-\beta_1}$$

where $\xi = -a_2(1-\beta_1)\delta$. The discounted value of the consumer surplus for research conducted at time t is then

$$PV^{cs}_t = \sum_{i=i_0+j_0}^{\infty} (1+\rho)^{-i} (1-\beta_1)^{-1} A^d_t P_t^{1-\beta_1} (1-G_t^{\xi\lambda^{i-i_0-j_0}})$$

$$= (1-\beta_1)^{-1} P_t Q_t \sum_{i=i_0+j_0}^{\infty} \{(1+\rho)^{-i} (1-G_t^{\xi\lambda^{i-i_0-j_0}})\}$$

where $\rho$ is the appropriate discount rate. The last equality results from equation (17). This infinite summation may be approximated by limiting the summation to a finite number of time periods when current R&D has "decayed" to the point where the future supply equation is close to the original supply equation. Once this is done for each period, expenditures may be subtracted and the IRR to consumer surplus may be calculated as the discount rate which equates

$$\sum_{n=0}^{N-1} (1+\rho)^{-n} (PV^{cs}_n - E_n) = 0$$

where N is the number of periods in the sample and $E_n$ is R&D expenditure in period n.[15]

In order to calculate the total economic benefit, the change in producer surplus is calculated and then added to consumer surplus. The shift of the supply curve induces a gross gain to producers (the area between the two supply curves and below price) and a gross loss to producers (a transfer to consumer surplus as price falls). The change in producer surplus in time period $t+i_0+j_0+k$ due to government R&D at time t is

$$\int_0^{P^e_{t+i_0+j_0+k}} A^s_t (G_t^{a_2\lambda^k} - 1) P^{a_1} \, dP - \int_{P^e_{t+i_0+j_0+k}}^{P_t} A^s_t P^{a_1} \, dP$$

$$= A^s_t (1+a_1)^{-1} (G_t^{\Psi\lambda^k} - 1) P_t^{1+a_1}$$

where $\Psi = a_2(\beta_1-1)\delta$. The discounted return to producers is

$$PV_t^{ps} = \sum_{i=i_0+j_0}^{\infty} (1+\rho)^{-i} (1+a_1)^{-1} A_t^s P_t^{1+a_1} (G_t^{\Psi\lambda^{i-i_0-j_0}}-1)$$

$$= (1+a_1)^{-1} P_t Q_t \sum_{i=i_0+j_0}^{\infty} \{(1+\rho)^{-i}(G_t^{\Psi\lambda^{i-i_0-j_0}}-1)\}$$

where the last equality results from equation (16). The infinite summation should again be approximated. The IRR in terms of total economic benefit is then calculated as the discount rate $\rho$ such that

$$\sum_{n=0}^{N-1} (1+\rho)^{-n} (PV_n^{cs} + PV_n^{ps} - E_n) = 0.$$

## CONCLUSIONS

In this paper the history of research evaluation in forestry has been discussed and estimated returns to research have been presented. These estimates are similar to estimates for agricultural research with the exception of Seldon (1987) and Seldon and Newman (1987).

Methodologies were then discussed. The residual method for calculating the IRR is an adaptation of the CS approach discussed in Norton and Davis (1981). The nonresidual method is an extension of the PF approach and uses the duality of production and cost functions. The former approach has appeal due to its simplicity and modest data requirements. The latter approach has extensive data requirements, but certain advantages:

1. It ties the CS and PF approach together, so that economies of scope in the research evaluation process can be realized.

2. It avoids the need for collecting data on input levels for the PF approach, and instead uses cost data which are often more readily available.

3. It imposes theoretically correct constraints on regression coefficients which in turn mitigates collinearity problems.

4. It avoids simultaneity bias which can occur when only a production function is estimated.[16]

5. It estimates the IRR from <u>all</u> research (not just successful research) in a particular industry.

6. It controls for other supply shifters in calculating the IRR. Through this control it credits R&D with retarding rising prices due to rising factor costs, but does <u>not</u> credit R&D when prices have fallen due to falling factor costs.

## FOOTNOTES

[1] Institutions involved in such studies include the North Central Forest Experiment Station, the Mississippi Agricultural and Forest Experiment Station, the Southern Forest Experiment Station, the Southeastern Forest Experiment Station, the Pacific Southwest Forest Experiment Station, the University of Minnesota College of Forestry, the Duke University School of Forestry and Environmental Studies, the Mississippi State University Department of Forestry, and the University of Washington College of Forest Resources.

[2] Excellent reviews are Norton and Davis (1981) and Davis (1981).

[3] Researchers at the University of Minnesota and the North Central Forest Experiment Station have divided their efforts between impact evaluations, and process evaluations while researchers at Duke University have concentrated on impact evaluations. See Bengston (1986).

[4] Forest products are often homogeneous or standardized by the government or industry, and entry costs are often low (with some exceptions such as particleboard and paper). Four-firm concentration ratios also are low; the largest four-firm concentration ratio for four-digit SIC Code forest industries in 1977 was 48 percent for both particleboard (SIC code 2492) and pulp mills (SIC code 2611). For 23 four-digit SIC code forest industries examined by the author, the average ratio was 23.7 percent.

[5] The index number variant of the CS approach is explained in Norton and Davis (1981).

[6] These private implementation costs for public R&D are distinct from private implementation costs for privately initiated R&D.

[7] Extension costs are not so large in the forest products cases as they are in agricultural cases and are usually included in the estimates of R&D since these estimates account for time to publish. There are fewer producers to contact than there are in agriculture and the producers of forest products often take the initiative in maintaining ongoing contact with the U.S. Forest Products Laboratory and experiment stations through visits and telephone calls.

[8] If one were less demanding of the data concerning the link between past research and current output, one could use a more general functional form as suggested, for instance, in Evenson (1981). But the focus on marginal productivity and output elasticity of R&D coupled with a general paucity of data often require the use of a more restrictive form. For recent examples, see Griliches and Mairesse (1984), Pakes and Schankerman (1984a) and Mansfield (1984).

[9] This is the form which performed most satisfactorily for Seldon (1985 and 1987) and Seldon and Newman (1987). The details of the more complex case are found in Seldon (1987).

[10] See, for example, Griliches and Mairesse (1984), Pakes and Schankerman (1984a), and Suzuki (1985).

[11] Empirical support for the first assertion is found in Pakes and Schankerman (1984b). The latter assertion is suggested in Griliches (1979, p. 102). Government research is often more basic than private firms would undertake due to the higher risk and longer payback period.

[12] A similar theoretical problem is considered in Nerlove and Arrow (1962). The authors solve the dynamic optimization problem and their results support the derivation of the supply curve presented here, including the fixed fraction assumption to follow.

[13] See Bullard and Straka (1987), Grabowski (1970), Hay and Morris (1979, p. 446), Mansfield (1968, p. 62) as well as National Science Foundation (1981) and annual reports of R&D expenditures in Business Week.

[14] Note that $\rho$ enters $VMP_{GM}$ as well as the infinite summation. A sample FORTRAN program which solves this problem iteratively is available from the author.

[15] The social discount rate $\rho$ enters each $PV_n^{cs}$ as well as the summation. A sample FORTRAN program to solve this problem is available from the author.

[16] For a discussion of this problem see Griliches (1979, pp. 106-8).

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