# Welfare Gains From Wood Preservatives Research

**Barry J. Seldon and William F. Hyde**

***Abstract*** *The economic productivity of publicly funded wood preservatives research from 1950 to 1980 exemplifies public research in the forest product industries We find a high internal rate of return for wood preservatives, nearly 300 percent The research investments would not have been made by private industrial investors, however, since the welfare gains are not captured by producers This provides justification for government involvement in research The marginal internal rate of return is negative, indicating that the internal rate of return would have been even higher with less funding*

***Keywords*** *Research and development, research evaluation, technical change, innovation, wood preservatives, forest products*

Wood preservatives research by USDA's Forest Products Laboratory (FPL) in Madison, WI, is an excellent example of public forestry research Since it was formed in 1910, the FPL has conducted much of the Nation's research on wood preservatives The returns to this research have not been studied previously An evaluation of the welfare effects of FPL wood preservatives research may be a useful platform from which to view forest product research in general

We examine the social productivity of FPL wood preservatives research in 1950-80 as an example of what may be a general case for public research in the forest product industries Our approach relies on econometric estimation of coefficients in a supply function derived from a standard production function using results from duality theory (*3*) [1] We then develop a method for estimating the internal rate of return (IRR) for public investments By estimating the effect of research and development (R&D) on the supply curve directly, we avoid the error of attributing all outward shifts in supply to R&D The method is similar in spirit to one used by White and Havlicek and follows Seldon's analysis of the softwood plywood (SWPW) industry (*19, 14*) His estimates of the IRR for public softwood plywood research range upward to a surprising 400 percent, depending on various possible estimates for private development costs associated with public research investments

This paper follows the earlier SWPW study in specifying a supply and demand system and determining the IRR to public research It then extends the method to calculate the value of the marginal product (VMP) and the marginal internal rate of return (MIRR) The duality between production and supply makes this extension possible A glance ahead to the results shows that we find a large IRR, comparable to that for the SWPW industry, but a potentially negative MIRR

## Background

The four-firm concentration ratio for the wood preservatives industry was in the 30-40 percent range throughout the period of our inquiry Therefore, the industry is competitive and we can define its supply function

Wood preservatives extend the life of treated wood products Therefore, one effect of wood preservatives research is on product quality Improved quality benefits consumers, but it is not the cost-reducing research reflected in most economic measures of technical change Wood preservatives are generally petroleum products, so the residuals created while treating wood with petroleum products are environmentally objectionable Therefore, much recent research in the wood preservatives industry has the objective of lowering levels of associated environmentally damaging residuals while still producing the same product These changes in residuals are also hidden from our output measure for the basic product Our eventual estimates of research productivity in the wood preservatives industry will be underestimated by the magnitude of product quality and environmental research impacts

## Supply and Demand

Studies focusing on the impact of R&D on productivity often employ a flexible form of the production function that allows analysts to consider the interactions among inputs (see, for example, *2, 8*) In this study, however, these interactions are not important considerations Therefore, we follow the advice of Griliches and use the Cobb-Douglas form (*5*) The exact form is the variant developed by Seldon (*14*) The production function at time $t$ is

$$Q_t = e^{\theta t} L_t^{\alpha_1} K_t^{\alpha_2} Y_t, \qquad (1)$$

where $Q$ is the quantity produced, $e$ is the base of natural logarithms, $\theta$ is the rate of disembodied technical change associated with $t$ (a proxy for disembodied

Seldon is with the School of Social Sciences, The University of Texas at Dallas Richardson, TX Hyde is an economist with the Resources and Technology Division, ERS USDA's Forest Service Southeastern Forest Experiment Station funded this research A Bruner and J Strauss provided research assistance The authors thank the reviewers of this article for their helpful comments

[1] Italicized numbers in parentheses cite sources listed in the References section at the end of this article

change as in *6*), $L$ is labor services, $K$ is capital services, and

$$Y_t = \prod_{i=i_0}^{\infty} (Z^{\eta}_{t-i} G^{\mu}_{t-i-j_0})^{\lambda^{i-i_0}}, \; i_0 > 0, \; j_0 \geq 0 \qquad (2)$$

is the accumulated research effort, $G$ is government R&D, and $Z$ is private R&D performed by the suppliers of the final product. The coefficient $\lambda$ is inversely related to the depreciation rate. Therefore, new research replaces older research and research obsolescence sets in more rapidly for smaller $\lambda$'s. Private R&D does not affect productivity for $i_0$ periods since it takes time for manufacturing plants to adopt the new knowledge. For similar reasons, government research does not affect productivity for $i_0+j_0$ periods. The lag until the initial impact of public R&D, $i_0+j_0$, must be at least as long as the lag preceding the initial impact of publicly induced private R&D, $i_0$, because producers must be made aware of the government R&D.

If firms in the wood preservatives industry are competitive profit maximizers, then the industry as a whole solves the problem

$$\max_{L_t, K_t} \; \pi_t = P_t Q(L_t, K_t, Y_t) - W_t L_t - R_t K_t - Z_t, \qquad (3)$$

where $\pi$ is profit, $P$ is the price of the good, and $W$ and $R$ are the wage rate and the cost of capital. We substitute the Cobb-Douglas form from equation 1 for the expression $Q$ in equation 3.

We solve equation 3 in terms of $L$ and $K$ and equate the results with zero in order to derive the supply function (*14*). The distributed-lag form of industry supply in logarithm form is

$$\begin{aligned} q_t = {} & (1-\lambda)\ln A + \gamma(\alpha_1+\alpha_2)(p_t - \lambda p_{t-1}) \\ & - \gamma\alpha_1(w_t - \lambda w_{t-1}) - \gamma\alpha_2(r_t - \lambda r_{t-1}) \\ & + \gamma[\theta t - \lambda\theta(t-1)] + \gamma\eta z_{t-1} + \gamma\mu g_{t-1} + \lambda q_{t-1}, \quad (4) \end{aligned}$$

where $q$, $p$, $w$, $r$, $z$, and $g$ denote the logarithms of $Q$, $P$, $W$, $R$, $Z$, and $G$, and $A$ and $\gamma$ are constant functions of $\alpha_1$ and $\alpha_2$. The definitions for the exogenous variables and data sources are

$q$ = a volume measure of preserved wood products (U.S. Department of Commerce *Census of Manufactures*, various years),

$p$ = own price (value of shipments divided by quantity, deflated by the 1967 producer price index) (U.S. Department of Commerce *Census of Manufactures*, various years),

$w$ = average hourly wage for production workers in wood preservatives (U.S. Department of Commerce *Census of Manufactures*, various years),

$r$ = real user cost of capital for wood products (Wharton Econometrics, personal correspondence),

$z$ = a proxy for private R&D expenditures: total revenue or price times quantity, since R&D is a fixed share of receipts (Mansfield, 1968, National Science Foundation, various issues), and

$g$ = government scientist months (various FPL attainment reports).

Public and private research lags of only 1 year give the best fit. The selection of these lags depends on a three-step process: (1) choice of the best linear two-stage least-squares (2SLS) fit for the lag in a linear version of the basic industry supply function (equation 4), (2) application of this chosen lag in the general supply equation, then (3) retests of the fully specified equation 4 with various similar lags. These 1-year lags are short, and perhaps are due to the fact that improved wood preservative technologies seldom require new equipment, or perhaps because the FPL association with the American Wood Preservers Association is so close that information dissemination is easy and rapid.[2] In any case, FPL personnel anticipate short lags in this industry, and our statistical tests support them. (These lags compare with the combined 2-year public and private lag in the SWPW industry (*14*).)

Generating the demand function is more difficult than the supply function. Creating a single general production function for the collection of heterogeneous consumers of preserved wood products (railroads, telephone companies, homebuilders, farmers, users of marine pilings) is difficult. Therefore, the preferred approach of deriving downstream consumers' demand from their profit functions could not be used. We experimented with several alternate demand forms. Specifications with a trend for the business cycle seem to work well. The intuitive justification is that consumers are so heterogeneous that, taken together, their expansions and contractions would reflect the general economy rather than any single element of it. The generalized demand function (with anticipated signs of coefficients in parentheses) is

$$q_t = \beta_0 + \underset{(-)}{\beta_1 p_t} + \underset{(+)}{\beta_2 b_t} + \underset{(?)}{\beta_3 \tau} + \underset{(?)}{\beta_4 \tau^2}, \qquad (5)$$

where $b$ is the log of net sales in manufacturing industries (*18*), and $\tau$ is the time variable proxy for exogenous changes in the level of use of treated lumber in downstream industries.

Net sales performs better than other proxies for the business cycle. The two time variables permit exponential adjustment in the industry but their antici-

[2]For examples, FPL researchers regularly serve on the American Wood Preservers Association staff, and 20 percent of all AWPA publications since 1905 have been written by FPL researchers.

pated signs are uncertain. Exponential decline is plausible for railroad consumption of crossties, and exponential expansion is even more likely for the use of many inorganic preservatives and for recent residential construction uses of treated lumber.

Table 1 shows the nonlinear two-stage least squares (NL2SLS) estimates for both the supply and the demand equations 4 and 5. All coefficients in the supply equation, except the coefficient for disembodied technical change, θ, have the anticipated sign. The coefficients on labor ($\alpha_1$), capital ($\alpha_2$), and public research ($\mu$) are not statistically significant at the 10-percent level.[3] There are three significant coefficients, those associated with private R&D ($\eta$), R&D depreciation ($\lambda$), and disembodied technical change ($\theta$). The independent variables explain 93 percent of all variance in the quantity supplied. Durbin's *h* statistic indicates that serial correlation is not a problem.

The insignificant coefficient on public research is disappointing but not surprising. The public research variable includes research efforts to reduce production cost, enhance product quality, and reduce negative externalities. We know that the latter two have little or no relationship to our measure of quantity. If they dominate and they are not serially collinear with cost-reducing research effort, then they are unrelated to the level of cost-reducing technical change, and we must anticipate an insignificant coefficient on public research effort. Of course, this masks statistical confidence in our estimates of cost-reducing public research.[4]

The negative sign on θ, reflecting negative disembodied technical change, is unusual, probably indicating that industrywide technical change has been unable to keep pace with either industrywide product standards or (more likely) increasing restrictions on petroleum product residuals. That is, research causing decreasing final levels of residuals may not have progressed rapidly enough to maintain industry production at the old levels existing before the new environmental restrictions. In any case, while this negative coefficient reflects unexplained relative industry decline, it has no impact on our measurement of the benefits of cost-reducing research.

All demand coefficients are statistically significant at the 5-percent level or better. The positive coefficient

**Table 1—NL2SLS estimates of demand and supply coefficients for wood preserving[1]**

| Supply | | Demand | |
|---|---|---|---|
| Labor | 0.037 | ($\beta_0$) | 11.611* |
| ($\alpha_1$) | (.085) | | (4.251) |
| Capital | .009 | Own price | −1.621* |
| ($\alpha_2$) | (.010) | ($\beta_1$) | (−.650) |
| | | Business | |
| $Z_{t-1}$ | .440** | activity | .929* |
| ($\eta$) | (.216) | ($\beta_2$) | (.255) |
| $G_{t-1}$ | .019 | time | −.056** |
| ($\mu$) | (.060) | ($\beta_3$) | (−.023) |
| lag | .322*** | time² | .002* |
| ($\lambda$) | (.218) | ($\beta_4$) | (.0004) |
| Time | −.014** | | |
| ($\theta$) | (−.007) | | |
| $R^2$ | 0.93 | | 0.64 |
| Durbin's *h* | −.05 | | |
| Durbin-Watson | | | 2.03 |
| Degrees of freedom | 25 | | 24 |

[1]Durbin's *h* tests for autocorrelation in the supply equation because it has a lagged endogenous term, while the Durbin-Watson statistic tests for autocorrelation in the demand equation.
Numbers in parentheses are standard errors.
* = Significant at the 1-percent level in a one-tailed test.
** = Significant at the 5-percent level in a one-tailed test.
*** = Significant at the 10-percent level in a one-tailed test.

on business activity, $\beta_2$, suggests that demand is procyclical, as expected. Demand is also price elastic, as expected, because there are many substitutes for treated wood products (untreated wood, metal, and concrete posts, for example). Differentiating the antilog of the log-linear demand function with respect to τ shows that demand decreased through the 14th period (1964) and increased thereafter. The lower $R^2$ is not surprising for this *ad hoc* specification of what should properly be a derived demand for a heterogeneous collection of consumers.

A low $R^2$, such as that found for the demand equation, may suggest that an important variable is missing from an equation. This led us to examine the error terms, because a missing variable will normally induce a pattern into the error term over time similar to the effect of autocorrelation. However, no such patterns existed in the error term, producing no evidence of a missing variable. Regardless of the potential estimation problem, any absent variable causes no problems for our analysis of research benefits so long as the potentially absent term is not collinear with the price coefficient. The price coefficient (more precisely, the price elasticity that derives from it) is the only demand information used in our eventual estimation of research benefits.[5]

## Calculating Returns

Following is a review of the general calculations underlying our eventual estimates of the net present

[3]Numerous analyses of R&D investments do not obtain statistical significance. In such cases, analysis in the agricultural research literature proceeds as long as the signs can be interpreted as satisfying economic reasoning.

[4]Since the coefficient associated with government R&D is insignificant, one might conclude that the true coefficient is zero. If so, then the gross benefits would be zero and the net returns would be negative since research would have no effect upon supply and price. But, in fact, producers have adopted the methods and it seems implausible to support that this adoption has no effect on supply. We believe our estimates are as accurate as can be obtained, given current methods.

[5]There are no econometric analyses of the wood preservatives industry known to us. Therefore, there are no comparable elasticity estimates to use to check our results.

value, IRR, VMP, and MIRR associated with public research expenditures. All elements build on our knowledge of the estimated supply and demand functions and the research-induced shifts in supply over time.

The supply and demand system in period $t + 1 + j$ ($j > 0$) due to a given level of R&D expenditure $G$ (the antilog of $g$) in period $t$ is

$$S_t G_t^{a_2\lambda^j} P_{t+1+j}^{a_1} = D_t P_{t+1+j}^{-a_3} \tag{6}$$

All variables, including $G$ for periods prior to $t$, remain at their previous levels. $Ln(S_t)$ and $ln(D_t)$ include the intercepts of the log linear supply and demand system at time $t$, $a_1 = (\alpha_1 + \alpha_2)/(1 - \alpha_1 - \alpha_2)$ is the supply elasticity, $a_2 = \gamma\mu$, and $-a_3 = \beta_1 < 0$ is the demand elasticity. Equation 6 determines the equilibrium future price $P^E$ in the $(t + 1 + j)$th period as $P^E_{t+1+j} = P_t G_t^{-\sigma a_2 \lambda^j}$, where $\sigma = 3(a_3 + a_1)^{-1}$.

The expressions for the present values of consumers' and producers' surpluses, $PV^{cs}$ and $PV^{ps}$, due to R&D in period $t$ are

$$PV_t^{cs} = (1-a_3)^{-1} P_t Q_t \sum_{i=1}^{\infty} (1+\rho)^{-i} (1 - G_t^{\sigma\lambda^{i-1}}), \tag{7}$$

and

$$PV_t^{ps} = (1+a_1)^{-1} P_t Q_t \sum_{i=1}^{\infty} (1+\rho)^{-i} (G_t^{\omega\lambda^{i-1}} - 1), \tag{8}$$

where $\rho$ is the discount rate, $\sigma = -a_2(1 - a_3)$, and $\omega = -\sigma$. The terms must be approximated by limiting the summations to the finite number of periods before the R&D contribution of the $t$th period depreciates sufficiently that the supply is again close to the original period supply. We limit the summation to 15 periods. Subtracting total (public plus induced private) R&D expenditures, $E_t$, from $PV_t^{cs}$ and $PV_t^{ps}$ yields the net present value of R&D in each period. Summing the discounted terms for each year in the period 1950-80 yields the net present value (NPV) of the entire research program. For example, for consumers' surplus

$$NPV^{cs} = \sum_{t=0}^{30} (1+\rho)^{-t} (PV_t^{cs} - E_t) \tag{9}$$

The IRR for equation 9 is the value of $\rho$ which equates net present value with zero.

We will soon derive the value of the marginal product for public R&D expenditures (VMP). In the VMP derivation, we will need an expression for the term $\partial Q/\partial E$, so we develop the expression first to preserve the continuity of the derivation of the VMP. Note that since output $Q$ is a function of public research effort $G$ (measured as scientist months), and since public research effort $G$ is a function of public expenditures $E$, we may use the chain rule to find that $\partial Q/\partial E = (\partial Q/\partial G)(\partial G/\partial E)$. $G$ (government scientist months) increases as $E$ increases, so $\partial G/\partial E$ is strictly increasing (hence monotonic) in $E$. Therefore, the inverse of $\partial G/\partial E$, which is $\partial E/\partial G$, exists. In fact, since $E_t = C_t G_t$ (where $C_t$ is the average cost of a scientist month in year $t$), it is easy to see that $\partial G/\partial E = 1/C_t$. Then, using $\partial Q/\partial E$ from above and the fact that $\partial G/\partial E = 1/C_t$, it follows that

$$\partial Q/\partial E = (1/C_t)(\partial Q/\partial G) \tag{10}$$

We next derive the VMP of R&D. The VMP of any input is simply the price of the output times the marginal product of the input. While the VMP of R&D expenditures may be treated much the same as the VMP of any other input for any single period, the effects of R&D can last many periods into the future. Therefore, the annual effects must be discounted and summed. The discounted VMP of public research conducted in time $t$ in terms of the additional output in period $t+1$ is

$$\begin{aligned} VMP_t^{s,t+1} &= P_{t+1} (\partial Q_{t+1}/\partial E_t)/(1+\rho) \\ &= P_{t+1} (\partial Q_{t+1}/\partial G_t)/[(1+\rho)C_t], \end{aligned}$$

(while $VMP_t^{s,t} = 0$ since the lag between research expenditures and its initial impact on output is 1 year, research in time $t$ has no effect on output in time $t$). In our Cobb-Douglas case, we can substitute for $\partial Q_{t+1}/\partial G_t$ in the previous equation to obtain the following.

$$\begin{aligned} VMP_t^{s,t+1} &= \mu P_{t+1} Q_{t+1}/[(1+\rho)G_t C_t] \\ &= \mu P_{t+1} Q_{t+1}/[(1+\rho)E_t] \end{aligned}$$

Similarly, for any period $t+1+m$, $m > 0$, we obtain the returns to research conducted in time $t$.

$$VMP_t^{s,t+1+m} = \lambda^m \mu P_{t+1+m} Q_{t+1+m}/[(1+\rho)^{(1+m)} E_t],$$

where the $\lambda^m$ accounts for R&D depreciation. The full VMP at time $t$ is the sum of these single-period returns.

$$VMP_t = \sum_{m=0}^{\infty} \lambda^m \mu P_{t+1+m} Q_{t+1+m}/[(1+\rho)^{(1+m)} E_t] \tag{11}$$

Thus, we could estimate the VMP for each investment period in the sample. It is more common, however, to report the geometric mean of the entire series of VMP's (see *5*, *11*).

The MIRR is the value of $\rho$ that equates the geometric means of equation 11 with unity. This conforms with the more general forms of the MIRR (*4*, *19*) since the weight associated with the current period is zero.

## R&D Cost Estimates

We need estimates of the direct costs of FPL research and also the public research-induced costs of private implementation The FPL can provide a history of its research effort Identifying the costs of private implementation is more difficult We develop two alternative estimates to suggest a range in which true implementation costs, and true returns to research, may fall

Suppose that each dollar of FPL expenditure necessitates an expenditure of $n$ private dollars per plant Total expenditure $E_t$ can be expressed as $E_t = (1 + nN_t)c_tG_t$, where $N_t$ is the number of mills and $c_t$ is the direct cost of a scientist month Thus, the $C_t$ of equation 10 equals $(1 + nN_t)c_t$

We constructed $c_t$ from Sonka and Padberg's (*15*) academic price index and Callaham's (*1*) estimated cost of a USDA Forest Service scientist year for 1977, and then we added overhead estimates supplied by the FPL (table 2) $N_t$ is from various issues of the *Census of Manufactures Industry Series*, with linear

**Table 2—FPL effort in wood-preserving research, 1950-80**

| Year | Scientist months | Cost per scientist month[1] | Total cost |
|---|---|---|---|
| | *Number* | *—Thousand dollars[2]—* | |
| 1950 | 36 | 5 20 | 187 |
| 1951 | 50 | 4 86 | 243 |
| 1952 | 47 | 5 12 | 240 |
| 1953 | 44 | 5 25 | 231 |
| 1954 | 43 | 5 31 | 228 |
| 1955 | 42 | 5 42 | 228 |
| 1956 | 61 | 5 39 | 329 |
| 1957 | 77 | 5 36 | 413 |
| 1958 | 78 | 5 37 | 419 |
| 1959 | 78 | 5 49 | 428 |
| 1960 | 73 | 5 61 | 410 |
| 1961 | 96 | 5 74 | 551 |
| 1962 | 123 | 5 85 | 720 |
| 1963 | 131 | 6 02 | 788 |
| 1964 | 138 | 6 16 | 850 |
| 1965 | 136 | 6 22 | 846 |
| 1966 | 122 | 6 25 | 762 |
| 1967 | 120 | 6 49 | 779 |
| 1968 | 122 | 6 61 | 806 |
| 1969 | 128 | 6 72 | 860 |
| 1970 | 94 | 6 86 | 645 |
| 1971 | 128 | 6 97 | 893 |
| 1972 | 141 | 7 03 | 991 |
| 1973 | 130 | 6 74 | 876 |
| 1974 | 97 | 6 73 | 604 |
| 1975 | 82 | 6 40 | 524 |
| 1976 | 119 | 6 27 | 746 |
| 1977 | 148 | 6 23 | 922 |
| 1978 | 126 | 6 27 | 790 |
| 1979 | 141 | 5 96 | 841 |
| 1980 | 89 | 5 46 | 486 |

[1]Includes overhead
[2]1967 dollars
Source FPL attainment reports

interpolations for missing years (The number of plants ranged from 262 in 1950 to 498 in 1980 )

The value of $n$, the induced private effort is the most uncertain part of the analysis We obtain a measure of $n$ from knowledge of a single representative case, and then test our research benefit estimates for sensitivity to variation in this measure

Our representative case is the visual screening techniques for examining wood prior to treatment [6] Industry implementation of these techniques began in 1968 Visual screening requires an additional employee per plant, which, with appropriate discounting, converts to a private expenditure of 12 cents (1967 dollars) per manufacturing plant for every public research dollar We will compare gross public wood preservatives research benefits with the sum of public research costs plus this additional induced private cost and with a 50-percent increase in this cost to 18 cents per manufacturing plant Greater induced private development costs imply lower net economic benefits and lower rates of return to public research

## Results: The Efficiency of Public Wood Preservatives Research

Table 3 displays most of our summary results for the two cases where publicly induced private development costs are 12 cents and 18 cents per manufacturing plant and for the range of social discount rates between 4 percent and 10 percent The next returns to producers are negative for both R&D cost alterna-

[6]Researchers at the FPL confirmed the selection of these techniques as representative in its requirement for industrial modification and development in each plant (L Gjovick, personal communication, Nov 1988 )

**Table 3—Returns to public investment in wood-preserving research, 1950-80**

| Multiplier | | Social discount rate 0 04 | 0 07 | 0 10 |
|---|---|---|---|---|
| | | *—Million dollars[1]—* | | |
| 0 12 | $NPV^{cs}$ | 86 1 | 61 9 | 49 1 |
| | $NPV^{ps}$ | –118 1 | –68 3 | –40 2 |
| | $NPV^{neb}$ | 384 1 | 251 9 | 179 4 |
| | $BC^{cs}$ | 1 16/1 | 1 16/1 | 1 17/1 |
| | $BC^{neb}$ | 1 85/1 | 1 85/1 | 1 87/1 |
| | $IRR^{cs}$ not reported multiple solutions exist | | | |
| | $IRR^{neb}$ = 293 percent | | | |
| 0 18 | $NPV^{cs}$ | –117 3 | –64 2 | –34 1 |
| | $NPV^{ps}$ | –321 6 | –194 4 | –123 4 |
| | $NPV^{neb}$ | 180 7 | 125 7 | 96 2 |
| | $BC^{cs}$ | 78/1 | 78/1 | 79/1 |
| | $BC^{neb}$ | 1 24/1 | 1 24/1 | 1 25/1 |
| | $IRR^{cs}$ not reported multiple solutions exist | | | |
| | $IRR^{neb}$ not reported multiple solutions exist | | | |

[1]1967 dollars

tives and for the full range of social discount rates Net producers' surplus is generally positive for only six or seven individual years in the 1950-80 period This means that producers would not have conducted this research themselves Net consumer gains are positive for the 12-cent private development cost case but negative for the 18-cent case, regardless of social discount rates in our range The combined net benefits to producers and consumers are positive in all cases (Recall that our calculations of net benefits to consumers ($NPV^{cs}$) and net benefits to producers ($NPV^{ps}$) are both net of research expenditures Therefore, the net benefit to society ($NPV^{neb}$) is greater than the sum $NPV^{cs}$ + $NPV^{ps}$ by the amount of total R&D expenditures because the sum subtracts total R&D expenditures twice Rows 1-3 and 8-10 in table 3 reflect this result ) The positive social gain, yet negative producer gain, justifies the public FPL research presence

Table 4 shows the annual sequence of net consumer and producer surpluses and net social gain for the single case of 12-cent private development costs and a social discount rate of 4 percent This table shows the periodic switching from positive to negative values that prevents us from obtaining solutions for the various internal rates of return in table 3 Table 4 shows why the benefit-cost ratio increases with greater social discount rates For example, net losses occur in later years for consumers and are, therefore, discounted more heavily than the larger net gains of the earlier years

Table 5 reports the periodic annual values of marginal products (VMP's), the average VMP, and the marginal internal rate of return (MIRR) Annual and average VMP's less than one and MIRR's less than zero indicate an overinvestment in public wood preservative research This observation is all the more true for more recent years during the 30-year period These were also years of rising petroleum product prices and the years of largest research investments in controlling environmental residuals Removing the costs of these latter environmental and product-quality research efforts may raise the MIRR to the positive range and remove the question of overinvestment

If we consider all public research investments to be of the cost-saving variety, then investments in wood preservative research would have been socially wise ($NPV^{neb}>0$) but would not have been made by private industrial investors ($NPV^{ps}<0$) It would have been even wiser, however, for the FPL to invest but at a lower total level each year (VMP<1), MIRR<0) The net social gains ($NPV^{neb}$) would have been greater than those we observed

When we acknowledge substantial product quality improvement and environmental investments in wood preservative research, then we know that our summary benefit measures are all lower estimates Returns to public wood preservative research were at least as great as those we reported for cost-reducing research, and our subjective judgment is that the net public gains may have been positive in all scenarios

**Table 4—Returns to wood preservatives research, by individual year (multiplier = 0 12, discount rate = 0 04)**

| Year | Net present value of returns to Consumers | Producers | Consumers and producers |
|---|---|---|---|
| | *Million dollars*[1] | | |
| 1950 | 12 0 | 4 6 | 22 7 |
| 1951 | 13 4 | 4 7 | 26 1 |
| 1952 | 13 8 | 4 9 | 26 9 |
| 1953 | 12 2 | 4 0 | 24 2 |
| 1954 | 11 0 | 3 3 | 22 4 |
| 1955 | 10 7 | 3 0 | 22 0 |
| 1956 | 11 3 | 1 8 | 25 2 |
| 1957 | 10 3 | – 1 | 25 6 |
| 1958 | 3 9 | –4 1 | 15 6 |
| 1959 | 4 6 | –4 0 | 17 1 |
| 1960 | 5 3 | –3 4 | 18 1 |
| 1961 | 4 | –8 8 | 13 7 |
| 1962 | –4 8 | –14 8 | 9 9 |
| 1963 | –5 8 | –16 8 | 10 2 |
| 1964 | –6 6 | –18 7 | 11 1 |
| 1965 | –7 1 | –19 3 | 10 8 |
| 1966 | –1 1 | –14 6 | 18 6 |
| 1967 | –1 0 | –15 2 | 19 6 |
| 1968 | – 5 | –15 6 | 21 6 |
| 1969 | –6 4 | –20 3 | 14 0 |
| 1970 | 2 8 | –10 9 | 22 8 |
| 1971 | –5 7 | –21 0 | 16 5 |
| 1972 | –6 7 | –23 7 | 18 1 |
| 1973 | –1 5 | –18 8 | 23 7 |
| 1974 | 14 6 | –4 1 | 41 8 |
| 1975 | 6 5 | –7 5 | 26 9 |
| 1976 | –1 9 | –17 7 | 21 1 |
| 1977 | 7 | –20 5 | 31 8 |
| 1978 | 11 4 | –11 8 | 45 2 |
| 1979 | 5 5 | –17 0 | 38 3 |
| 1980 | 19 7 | – 3 | 48 9 |

[1]1967 dollars

## References


1 Callaham, R Z *Criteria for Deciding About Forestry Research Programs* U S Dept Agr , Forest Service, Gen Tech Rep WO-29, 1981

2 Caves, D , L Christensen, and J Swanson "Productivity Growth, Scale Economies and Capacity Utilization in U S Railroads, 1955-1974," *American Economic Review* Vol 70, No 3, 1981, pp 994-1,002

3 Chambers, R G *Applied Production Analysis A Dual Approach* Cambridge, England Cambridge University Press, 1988

**Table 5—Annual and average VMP's and MIRR's of public wood-preserving research**

| Year | Social discount rate | | | | | |
|---|---|---|---|---|---|---|
| | Multiplier = 0 12 | | | Multiplier = 0 18 | | |
| | 0 04 | 0 07 | 0 10 | 0 04 | 0 07 | 0 10 |
| | | | *Dollars*[1] | | | |
| 1950 | 1 02 | 0 98 | 0 94 | 0 69 | 0 66 | 0 64 |
| 1951 | 84 | 80 | 77 | 56 | 54 | 52 |
| 1952 | 86 | 83 | 80 | 58 | 56 | 54 |
| 1953 | 82 | 79 | 76 | 55 | 53 | 51 |
| 1954 | 77 | 74 | 71 | 52 | 50 | 48 |
| 1955 | 76 | 73 | 70 | 51 | 49 | 47 |
| 1956 | 58 | 56 | 54 | 39 | 37 | 36 |
| 1957 | 47 | 45 | 44 | 32 | 31 | 29 |
| 1958 | 35 | 34 | 32 | 24 | 23 | 22 |
| 1959 | 36 | 35 | 33 | 24 | 23 | 22 |
| 1960 | 38 | 37 | 35 | 26 | 25 | 24 |
| 1961 | 27 | 26 | 25 | 18 | 18 | 17 |
| 1962 | 21 | 21 | 20 | 14 | 14 | 13 |
| 1963 | 21 | 20 | 19 | 14 | 13 | 13 |
| 1964 | 20 | 20 | 19 | 14 | 13 | 13 |
| 1965 | 20 | 19 | 19 | 14 | 13 | 13 |
| 1966 | 25 | 24 | 23 | 17 | 16 | 15 |
| 1967 | 25 | 24 | 23 | 17 | 16 | 15 |
| 1968 | 25 | 24 | 23 | 17 | 16 | 16 |
| 1969 | 21 | 20 | 20 | 14 | 14 | 13 |
| 1970 | 30 | 28 | 27 | 20 | 19 | 18 |
| 1971 | 22 | 21 | 20 | 15 | 14 | 14 |
| 1972 | 21 | 21 | 20 | 14 | 14 | 13 |
| 1973 | 24 | 23 | 22 | 16 | 16 | 15 |
| 1974 | 39 | 38 | 36 | 26 | 25 | 24 |
| 1975 | 34 | 33 | 32 | 23 | 22 | 21 |
| 1976 | 24 | 23 | 23 | 16 | 16 | 15 |
| 1977 | 25 | 24 | 23 | 17 | 16 | 15 |
| 1978 | 32 | 30 | 29 | 21 | 20 | 20 |
| 1979 | 38 | 26 | 25 | 18 | 18 | 17 |
| 1980 | 46 | 44 | 42 | 31 | 29 | 28 |
| Average VMP | 35 | 34 | 32 | 24 | 23 | 22 |
| MIRR | | < 0 (average VMP at zero discount rate = 0 37) | | | < 0 (average VMP at zero discount rate = 0 25) | |

[1] 1967 dollars


4 Davis, J "A Comparison of Procedures for Estimating Returns to Research Using Production Functions," *Australian Journal of Agricultural Economics* Vol 25, No 1, 1980, pp 60-72

5 Griliches, Z "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *American Economic Review* Vol 54, No 6, 1964, pp 961-74

6 ______ "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics* Vol 10, No 1, 1979, pp 92-116

7 Jakes, P J "Research Evaluation in the U S Forest Service Opinions of Research Managers," *Research Policy* Vol 17, No 5, 1988, pp 283-92

8 Lyu, S-J , F White, and Y-C Lu "Estimating Effects of Agricultural Research and Extension Expenditures on Productivity A Translog Production Function Approach," *Southern Journal of Agricultural Economics* Vol 16, No 2, 1984, pp 1-8

9 Mansfield, E *The Economics of Technological Change* New York Norton, 1968

10 National Science Foundation *Research and Development in Industry* Various issues Washington, DC

11 Peterson, W L "Returns to Poultry Research in the United States," *Journal of Farm Economics* Vol 49, No 3, 1967, pp 656-69

12 Ruttan, V L "Agriculture Research and the Future of American Agriculture," *The Future of*

*American Agriculture as a Strategic Resource* (S S Batie and R G Healy, eds ) Washington, DC The Conservation Foundation, 1980

13 Seldon, B J "Economic Analysis of Forestry Research Synthesis and Methodology," *Evaluating Agricultural Research and Productivity* (W B Sundquist, ed ) Misc Pub 52-1987, St Paul Minn Agr Exp Sta & Univ of Minn , 1987

14 ______ "A Nonresidual Estimation of Welfare Gains from Research The Case of Public R&D in a Forest Product Industry," *Southern Economic Journal* Vol 54, No 1, 1987, pp 64-80

15 Sonka, S T , and D I Padberg *Estimation of an Academic Research and Development Price Index* Agr Econ Bull 79 E-100, Urbana Univ of Illinois, 1979

16 U S Department of Commerce, Bureau of Census *Statistical Abstract of the United States 1984* 1984

17 U S Department of Commerce. *Census of Manufactures, Industry Series Wooden Containers and Miscellaneous Wood Products* Various years

18 U S Government Printing Office *Economic Report of the President* 1987

19 White, F , and J Havlicek "Optimal Expenditures for Agricultural Research and Extension Implications of Underfunding," *American Journal of Agricultural Economics* Vol 64, No 1, 1982, pp 47-55