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ABSTRACT. Forestry research is conducted by state and federal agencies and by many private firms. Studies of research productivity and efficiency are increasingly common in forestry, due to the greater scale of research activity, and increasing competition for both public and private funds. Research evaluations rely on accurate measures of research inputs and outputs. This article presents an equation to predict research inputs for five major firms in the U.S. pulp and paper industry. Pulp and paper research by major U.S. companies is very closely related to corporate sales each year. The relationship empirically supports important assumptions that have been used in studies evaluating aggregate returns to research. FOREST SCI. 32:936–943.

ADDITIONAL KEY WORDS. Research efficiency, economic theory, research management, econometrics.

RESEARCH and development (R&D) is an integral part of the U.S. economy. Research is sponsored by many federal and state agencies and by many companies and foundations in the private sector. In recent years, company-funded industrial R&D spending has increased at rates well above the general level of price inflation. From 1976 to 1981, for example, it increased from $17.4 to $35.4 billion (National Science Foundation 1983), an average annual increase of 12.5%. Federal support has increased for nondefense basic research, but has decreased for applied research and development (Keyworth 1984).

The increasing scale of scientific activity and greater competition for public and private funds have drawn attention to the economic effectiveness of research and the research-innovation system. In many industries, rates of return and benefit-cost ratios have been estimated to evaluate programs. Research evaluations in agriculture, forestry and other natural resource fields, for example, were listed by Westgate (1984). Recent studies in forestry are summarized in Risbrudt and Jakes (1985).

Studies of research efficiency require reliable measures of research inputs and outputs. R&D spending for particular industries is an important variable for studies of the benefits and costs or rates of return from particular types of research and development. Very simple relationships between corporate R&D and corporate output or total sales have been shown for some industries (Mansfield 1968). In a recent study of returns to research in the U.S. plywood industry, Seldon (1985) assumed that private firms spend a fixed fraction of their total sales each year on R&D. Seldon observed that such behavior has often been noted empir-

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TABLE 1. Percent of total sales allocated to R&D by five major U.S. paper companies.

Year	Boise Cascade	Crown Zellerbach	Owens Illinois	Scott Paper	Weyer-haeuser	Ave.
			percent			
1975	0.16	0.45	1.28	2.03	0.95	0.95
1976	0.17	0.43	1.32	1.78	1.06	0.93
1977	0.17	0.43	1.13	1.70	1.41	0.96
1978	0.17	0.40	1.00	1.55	1.34	0.90
1979	0.18	0.42	0.65	1.51	1.02	0.74
1980	0.17	0.41	0.69	1.50	1.15	0.77
1981	0.18	0.37	0.73	1.36	1.21	0.77
1982	0.15	0.48	0.69	1.31	1.17	0.80
1983	0.17	0.45	0.82	1.19	0.96	0.72
1984	0.21	0.49	0.75	1.40	0.82	0.72
10-year ave.	0.17	0.43	0.90	1.53	1.11	

ically, and shows that it is optimal "for a competitive firm with Cobb-Douglas technology in a dynamic setting under conditions of steady growth." In this article, we predict corporate R&D spending with firm size in pulp and paper manufacturing, an industry that has been characterized as oligopolistic (Gregory 1972). Our test of a simple fractional relationship could not be rejected.

MODEL SPECIFICATION

Economic theory suggests that R&D may induce corporate growth, and that larger companies may fund proportionately more research. As stated by Kamien and Schwartz (1982) "... the intensity of inventive activity and firm size are likely

TABLE 2. Estimated coefficients and regression criteria for equation (3).

Parameter	Estimated value and standard error
β'_{01}	−0.078 (0.782)
$\tilde{\beta}'_{02}$	−1.831* (0.118)
$\tilde{\beta}'_{03}$	−0.910* (0.122)
$\tilde{\beta}'_{04}$	−0.212* (0.089)
$\tilde{\beta}'_{05}$	0.362 (0.184)
β_1	1.050* (0.233)

Regression criteria

$F = 235.7$	$\bar{R}^2 = 0.960$	$s_{y \cdot x} = 0.168$(ln scale)

where

coefficient standard errors are in parentheses,
* indicates significantly different from zero ($\alpha = 0.05$),
$\bar{R}^2$ is the adjusted coefficient of determination, and
$s_{y \cdot x}$ is the standard error of the estimate.

TABLE 3. Parameter estimates and regression criteria for equation (6).

Parameter**	Estimated value and standard error
β''_{01}	0.16567
	(0.43636)
$\tilde{\beta}''_{02}$	−2.18989*
	(0.38741)
$\tilde{\beta}''_{03}$	−0.70495*
	(0.08829)
$\tilde{\beta}''_{04}$	−0.20736
	(0.22838)
$\tilde{\beta}''_{05}$	−0.002770
	(0.23198)
β_1	0.94563*
	(0.21669)

Regression criteria

F	$\bar{R}^2$	$s_{y \cdot x}$
121.129	0.932	0.116

* Significantly different from zero ($\alpha = 0.05$).

** Since the intercept terms in equation (6) are multiplied by $(1 - \rho_i)$, $\hat{\beta}'_{0i}$ is obtained from $\hat{\beta}''_{0i}$ by: $\hat{\beta}'_{0i} = \hat{\beta}''_{0i}/(1 - \rho_i)$.

to be mutually determined variables . . . ." They observe, however, that although economic theory suggests models with systems of simultaneous equations, very few such models have been estimated (Mueller 1967; Loeb 1983, 1984). Kamien and Schwartz (1982) attribute the number of single-equation models to a lack of appropriate data, however, rather than to economic theory. Our analysis was restricted to single equations because of limited observations on individual company research in the U.S. pulp and paper industry. We therefore assume one-way causal flow in our test for a simple fractional relationship between R&D activity and firm size.

We used a Cobb-Douglas specification for predicting research funding:

$$\text{R\&D} = \beta_0 S^{\beta_1} \mu \qquad (1)$$

where

R&D is a measure of a firm's research and development effort in one year, S is a measure of corporate size or output, and β_0 and β_1 are parameters to be estimated.

The model was applied to research funding in oligopolistic industries by Worley (1961) and by Hamburg (1964). More recent studies of industrial R&D also include equation (1) in their tests of single-equation models (Loeb and Lin 1977, Loeb 1983).

DATA AND ESTIMATION RESULTS

Possible measures of R&D effort and corporate size include assets, numbers of employees, expenditures, and ratios that reflect R&D intensity. The most popular measures in previous studies, however, are dollars spent on R&D and total company sales. *Business Week* reports R&D expenditures and measures of corporate size and performance for approximately 700 U.S. companies each year. The data are obtained from the Form 10-K statements filed annually by public corporations with the Securities and Exchange Commission. Each of the companies listed in the *Business Week* summary has sales of at least \$50 million or R&D expenses of at least \$1 million.

Of the companies listed by *Business Week* as paper and container companies, we analyzed R&D expenditures for five, which appear each year from 1975 to 1984. The companies are listed in Table 1, with percentages of total sales allocated to R&D over the 10-year period. Total sales and R&D expenditures for each company form a cross-section, and the years 1975 to 1984 represent a 10-year time series. We therefore had 50 cross-section, time-series observations of total sales and R&D spending in the pulp and paper industry. The producer price index was used to express all values in 1975 dollars.

Pooled cross-section, time-series data can be analyzed in several ways (Judge et al. 1980). We chose the multiple covariance model for the paper industry data, using dummy variables to shift regression intercepts for different firms.[1] Equation (1) was estimated with intercept:

$$\beta_{01} + \sum_{i=2}^{5} \tilde{\beta}_{0i} D_i$$

where

β_{01} = intercept term for firm 1,
D_i = 1 for firm i, zero otherwise, $i = 2, 3, 4, 5$, and
$\beta_{01} + \tilde{\beta}_{0i}$ = intercept terms for firms 2 through 5 ($\tilde{\beta}_{0i}$ represents the intercept difference for firms 2 through 5).

Equation (1) was therefore replaced bv

$$\text{R\&D} = \left(\beta_{01} + \sum_{i=2}^{5} \tilde{\beta}_{0i} D_i\right) S^{\beta_1} \mu \qquad (2)$$

and was estimated as

$$\ln(\text{R\&D}) = \beta'_{0i} + \sum_{i=2}^{5} \tilde{\beta}'_{0i} D_i + \beta_1 \ln S + \mu' \qquad (3)$$

where

R&D is corporate R&D funding (units are millions of 1975 dollars),
S is corporate total sales (units are hundred millions of 1975 dollars), and
β'_{0i}, $i = 1, 2, \ldots, 5$ in (3) is related to β_{0i} by
$\beta_{0i} = e^{\beta'_{0i}}$ (or $\beta'_{0i} = \ln \beta_{0i}$), and $\mu' = \ln \mu$.

Ordinary least squares regression results are presented in Table 2. The F value for equation (3) indicates a significant relationship between R&D and total sales for the five companies. The coefficient for β_1 is positive and is significant (α = 0.05).

With the estimated coefficients in Table 2, equation (3) can be applied to the five pulp and paper firms from 1975 to 1984. Although we did not statistically

[1] Parameter differences were assumed constant over *time,* but were tested between *firms.* The null hypothesis that slope differences between firms were zero could not be rejected ($\alpha = 0.05$), yet intercept differences were significant. The error components model was not used due to the restrictive assumptions outlined by Swamy (1974) and Judge et al. (1980).

TABLE 4. Estimated model of R&D funding for five major U.S. pulp and paper companies, 1975–1984.

$R\&D_{i,t} = e^{\hat{\beta}'_{0i}} S_{i,t}^{0.94563}$

where

$R\&D_{i,t}$ is R&D funding predicted for company i in year t (millions of 1975 dollars),
$S_{i,t}$ is total sales for company i in year t (hundred millions of 1975 dollars),
e is the base of the natural logarithms, and
$\hat{\beta}'_{0i} = -1.5954144$ for Boise Cascade,
−0.6828392 for Crown Zellerbach,
−0.1318839 for Owens-Illinois,
0.4554013 for Scott Paper, and
0.2793923 for Weyerhaeuser.

test estimated values for autocorrelation among the error terms,[2] positive autocorrelation was indicated by inspecting the residual pattern over time for each firm. Econometrics literature poses several possible causes and corrections for autocorrelation. An obvious potential cause in equation (3) is that a significant explanatory variable (or variables) may be omitted. The equation has only one regressor, yet corporate R&D in the pulp and paper industry may well rely on other important factors from year to year: current and past profits, management changes, government policies, etc. We did not add variables to equation (3), but estimated parameters with ordinary least squares applied to the data after generalized differencing (Pindyck and Rubinfeld 1981).

For the multiple covariance model, generalized differencing involves correcting for autocorrelation for each company. For equation (3), first-order autocorrelation of the log-linear model may be stated as:

$$\mu'_{it} = \rho_i \mu'_{i,t-1} + \gamma_{it}, \; i = 1, 2, 3, 4, 5 \tag{4}$$

If ρ_i is known ($i = 1, 2, 3, 4, 5$) the log-linear form of (3) can be altered to a model with independent error terms. In particular, since (3) holds for all time periods, the model can be written:

$$\ln(R\&D_{i,t-1}) = \beta'_{0i} + \sum_{i=2}^{5} \tilde{\beta}'_{0i} D_i + \beta_1 \ln S_{i,t-1} + \mu'_{i,t-1} \tag{5}$$

Multiplying equation 5 by ρ_i and subtracting from (3) yields the transformation with independent error terms:

$$\ln(R\&D_{i,t})^* = \left(\beta'_{0i} + \sum_{i=2}^{5} \tilde{\beta}'_{0i} D_i\right)(1 - \rho_i) + \beta_1 \ln S_{i,t}^* + \gamma_{it}^* \tag{6}$$

where

$$\ln(R\&D_{i,t})^* = \ln(R\&D_{i,t}) - \rho_i \ln(R\&D_{i,t-1}),$$
$$\ln S_{i,t}^* = \ln S_{i,t} - \rho_i \ln S_{i,t-1},$$

and

$$\gamma_{i,t}^* = \mu'_{i,t} - \rho_i \mu'_{i,t-1}.$$

[2] Simultaneous relationships between R&D and firm size are suspected as the underlying structural model, although our data were not extensive enough to reliably estimate such a system. Durbin-Watson test procedures for autocorrelation require no mutually determined variables, or lagged endogenous variables, however, and therefore were not applied.

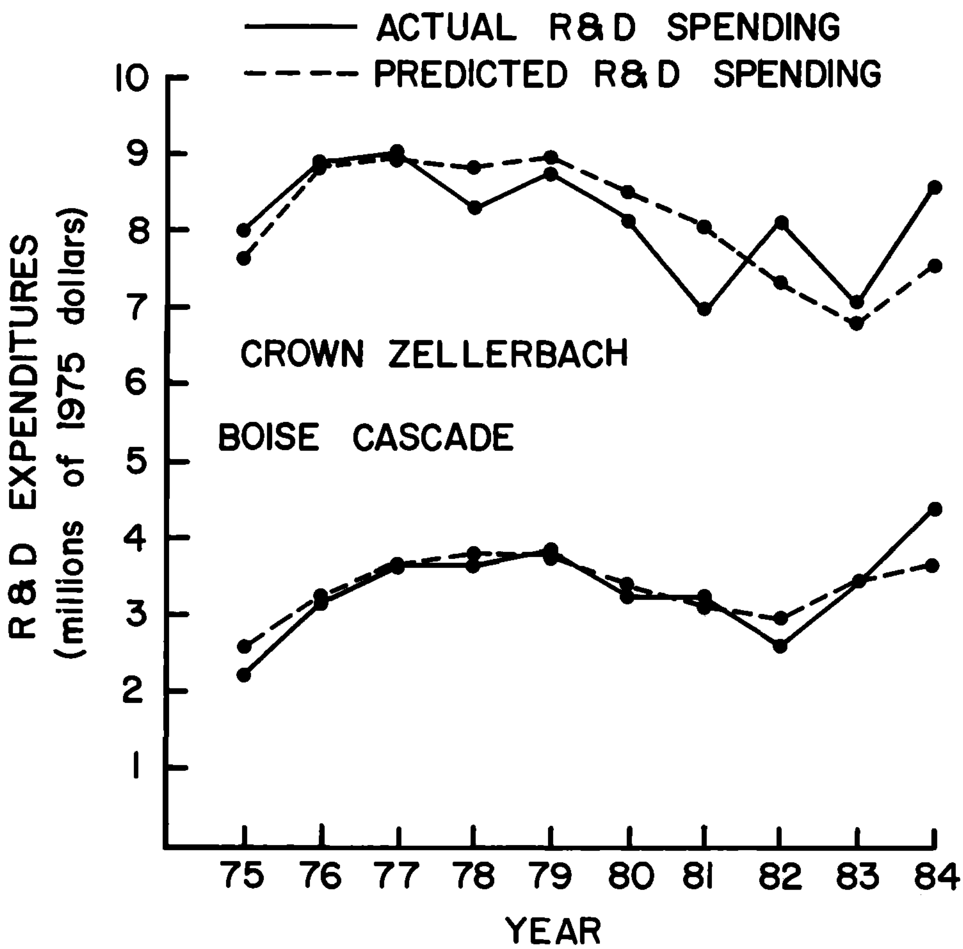

FIGURE 1. Actual and predicted R&D spending, Crown Zellerbach, and Boise Cascade.

After estimating ρ_i for each company,[3] R&D and total sales data were transformed, and parameters of equation (6) were estimated with ordinary least squares. Results are presented in Table 3. Table 4 presents parameter estimates for each company in the original, nonlogarithmic form of the model.

Predictions from Table 4 are plotted in Figure 1 for Boise Cascade and Crown Zellerbach. These companies had the most consistent R&D funding and total sales relationships over the 10-year period (Table 1). Figure 1 illustrates the model's relative accuracy over the period. For some pulp and paper companies, highly accurate R&D estimates would require a more complicated model. The consistent over- and underestimation of R&D for Crown Zellerbach over the period, for example, indicates that important variables may be omitted from the

[3] $$\hat{\rho}_i = \frac{\sum_{t=2}^{10} \hat{\mu}'_{i,t}\hat{\mu}'_{i,t-1}}{\sum_{t=2}^{10} \hat{\mu}'^{2}_{i,t-1}}, \qquad \text{for } i = 1, 2, 3, 4, 5,$$

where $\hat{\mu}'_{i,t}$ and $\hat{\mu}_{i,t-1}$ are error terms from the ordinary least squares estimation of equation 3.

predictive equation. For other companies, like Boise Cascade, model predictions reflect R&D spending much more closely over the ten years.

R&D AND TOTAL SALES

From 1975 to 1984, corporate R&D for five major U.S. paper companies was closely related to total sales. The functional form between R&D and total sales in equation (3), referred to as Cobb-Douglas (Nerlove 1964), allows us to test for a simple, fractional relationship between R&D and annual sales.

Where β_{0i} represents the intercept term for company i, ignoring the error term, equation (3) can be written as:

$$R\&D_{i,t} = \beta_{0i} S_{i,t}^{\beta_1} \tag{7}$$

For Cobb-Douglas functions, constants such as β_1 in equation (7) represent economic elasticities. The elasticity of $R\&D_{i,t}$ with respect to annual sales of the company represents the expected *change* in $R\&D_{i,t}$ for a small change in $S_{i,t}$ from a given level of total sales.

To investigate the assumption that a simple fractional relationship exists between R&D and total sales for pulp and paper companies, we simply test the null hypothesis that $\beta_1 = 1$. The t-value for testing $H_o:\beta_1 = 1$ is:

$$\frac{.94563 - 1}{.21669} = -0.25091.$$

Based on our data for five pulp and paper companies, the hypothesis that $\beta_1 = 1$ cannot be rejected. The evidence supports previous studies of R&D in other industries, studies that have assumed that industrial R&D can be estimated as a simple fraction of corporate total sales. For the pulp and paper industry, the fraction varies from company to company. Our analysis reflected individual companies to increase degrees of freedom in estimating β_1. Since different ratios of R&D and total sales exist between firms, results based on aggregate data should not be applied to individual companies.

There is also evidence that corporate R&D emphasis changes with time. Corporate averages in Table 1 decline over the 10 years. Parameters were assumed constant over time, however, since our data were for a relatively short period. As discussed by Mansfield (1968), in the short run there should be a tendency for observed R&D to total sales ratios to be fairly constant. Over longer periods, however, firms change their emphasis on R&D based on such factors as expected profitability and competitive pressures.

Research management and evaluation become critical when government agencies or corporate divisions compete for limited R&D funds. As competition and R&D spending grows, knowledge of the research/innovation system for various industries and types of research must also grow. Our study of pulp and paper supports evidence that private-sector R&D spending is proportionate to total company sales in certain industries. There are significant differences, however, in the relative emphasis placed on R&D between firms in the pulp and paper industry.

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