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Productivity growth, environmental regulations and the composition of R&D

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The average annual rate of productivity growth in the United States has fallen since the mid-1960s. One factor often cited for this trend is the slowdown in the level of R&D spending. In considering this factor, many researchers have examined the correlation between productivity growth and R&D spending and found that it was positive through the 1960s but near zero in the 1970s. This latter result has raised the question as to whether the productivity of R&D has collapsed. Evidence is presented in this article that the collapse of R&D in empirical productivity equations is conceptually misleading because a significant portion of R&D was directed in the 1970s toward compliance with environmental regulations. These expenditures appear to be negatively related to measured productivity growth.

1. Introduction

■ The decline in productivity growth in the United States is well documented. As seen from Table 1, the average annual rate of change in productivity fell since the mid-1960s. This deceleration has received considerable attention by policy makers and researchers, and the reason is simple: productivity growth is believed to be the dominant source of our economic well being. Fabricant (1978), for example, elaborated on this belief in testimony before Congress. Higher productivity, he noted, is essential to a higher standard of living and vital to a sound international, economic, and political position.

Many factors have been cited as contributing to the slowdown in productivity, such as changes in energy prices, regulations, capital intensity, and workers' hours and attitudes.[1] In this article, I focus on the curtailment in R&D expenditures. Total R&D as a percent of GNP peaked at 3.0% in 1964, then fell to 2.3% by 1975 and to even a slightly lower level by 1977. It has been estimated that this decline may trough at 2.0% by 1985 (Kuper, 1978). Kendrick (1978) refers to R&D as "the fountainhead of productivity advance" and advocates providing industry tax-related incentives to reverse this trend.[2]

There is, however, some disagreement regarding the quantitative impact of the R&D decline on *measured* productivity growth. On the one hand, Nadiri (1980) estimates that the slowdown in the stock of R&D (through the slowdown in R&D spending) may account for as much as one-third of the productivity decline in the economy since 1973. On the other hand, Denison (1979) and Griliches (1980b) aver that the slowdown in R&D is not a significant factor; at best it accounts for one-tenth of the decline in productivity (Griliches, 1980b).

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[1] See Christainsen, Gollop, and Haveman (1980) for an excellent review of this literature.

[2] The Economic Recovery Act of 1981 provides a 25% tax credit for increases in the base (calculated as a three-year average) of a firm's nominal R&D expenditures. For a detailed discussion of R&D tax credits, see Mansfield (1981).

TABLE 1 **Average Annual Rate of Growth in Labor Productivity (in percent)**

	Private Business Sector		
1947–66[a]	3.44	1948–65[b]	3.32
1966–73	2.15	1965–73	2.32
1973–77	1.49	1973–78	1.20
	Private Nonfarm Business Sector		
1947–66[a]	2.83	1948–65[b]	2.77
1966–73	1.87	1965–73	2.02
1973–77	1.30	1973–78	1.09
	Manufacturing Sector		
1960–65[c]	3.40	1948–65[b]	3.13
1965–73	2.80	1965–73	2.47
1973–77	1.40	1973–78	1.70

[a] Mark (1978).
[b] Norsworthy, Harper, and Kunze (1979).
[c] Griliches (1980b).

One alternative hypothesis has been offered by Griliches (1980b). The hypothesis is that it is not the slowdown in R&D that is important for explaining the slowdown in productivity growth, but rather the "collapse" in the productivity of R&D itself that should be considered. This view is based, in part, on the empirical finding of a positive and significant correlation between R&D and measured productivity growth in the 1960s and a zero correlation in the 1970s.[3]

The thesis of this article is that the empirical collapse in the productivity of R&D in the 1970s is conceptually misleading. During that time period the activities under the rubric of R&D have become more heterogeneous: some of the activities involve types of R&D whose output is simply not measured by a standard productivity index. One such category is R&D directed toward compliance with environmental regulations.[4]

The need for environmental regulations, pollution control in particular, began to receive Congressional attention shortly after World War II—the 1948 Water Pollution Control Act and its 1956 Amendments, the 1955 Air Pollution Control Act, and the 1963 Clean Air Act—but this early legislation did not impose restrictive costs on industry. It was the more recent regulations that did—the 1965 Water Quality Act, the 1965 Motor Vehicle Air Pollution Control Act, the 1967 Air Quality Act, the 1970 Clean Air Amendments, and the 1972 Water Pollution Control Act Amendments. In general, the effect of environmental regulations on production costs can be ignored before 1967 (Denison, 1978). Since 1967 environmental compliance has caused the capital-related costs of production to rise significantly. The Industrial Research Institute estimates that R&D expenditures allocated by all industry for environmental improvements grew at an average annual rate of 15.4% between 1974 and 1977 (Manners and Nason, 1978). Over that time

[3] Examples of studies concluding that such a zero relationship existed during the 1970s are Agnew, Wise, and Tapiero (1980) and Link (1981b). An opposite conclusion was reached by Griliches and Lichtenberg (1981).

[4] Some researchers, such as Abramowitz (1981, p. 6), contend that a portion of the recent productivity slowdown "is attributable to the diversion of resources to comply with environmental regulation and safety requirements. . . ." This article is not principally concerned with measuring the quantitative effects of environmentally related R&D on the productivity slowdown. Rather, its focus is on the apparent collapse in the productivity of R&D owing to the inclusion of nonproductivity-related activities in the measurement of R&D.

period industrial R&D, as a total, grew only 9.4%. Thus, it may be the change in the composition of R&D, rather than the level, that is a culprit in the productivity growth slowdown of the 1970s.

2. The statistical analysis

■ Studies relating R&D expenditures to productivity growth are usually formulated on the assumption that the firm (or unit of analysis) operates according to a three-factor production function:[5]

$$Y = AF(L, K; T), \tag{1}$$

where Y is output, A is a neutral disembodied shift parameter, L and K are measures of the stock of labor and capital, respectively, and T is a stock of technical capital or technical knowledge.

If equation (1) has the form of a Cobb-Douglas production function, as is traditionally assumed, the model becomes:

$$Y = A_0 e^{\lambda t} T^{\alpha} L^{\beta} K^{(1-\beta)}, \tag{2}$$

where A_0 is a constant, λ is a parameter for the rate of disembodied growth, and α and β are output elasticities. Constant returns to scale are assumed with respect to L and K.

Differentiating equation (2) with respect to time, t, and rearranging terms yield a relationship between total factor productivity, TFP, and the rate of change in technical knowledge:

$$TFP = \dot{Y}/Y - \beta(\dot{L}/L) - (1 - \beta)\dot{K}/K = \lambda + \alpha(\dot{T}/T), \tag{3}$$

where $\alpha = (\partial Y/\partial T)\cdot(T/Y)$. Substituting this expression for α into equation (3) and assuming that the firm's net investment in the stock of technical knowledge, $\dot{T}$, can be approximated by its total R&D expenditures, RD, yield:

$$TFP = \lambda + \rho(RD/Y), \tag{4}$$

where $\rho = (\partial Y/\partial T)$ is interpreted as the marginal product of technical capital (Terleckyj, 1974, 1980; Griliches, 1980a; Mansfield, 1980; Link, 1980, 1981b).

Here a stochastic version of equation (4) is estimated by using data for 97 U.S. manufacturing firms, the nature of which is discussed below. TFP is measured as the growth rate in residually calculated productivity between 1975 and 1979. First, a productivity index, $g_t = \ln Y_t - b \ln L_t - (1 - b) \ln K_t$, was calculated for each firm, $t = 1975$–1979. The principal data source for these calculations was Compustat. Output, Y, was measured as net sales, defined as gross sales and other operating revenue less discounts, returns, and allowances, deflated by an industry-specific producer price index (Bureau of Labor Statistics). Labor, L, was represented by the total number of employees as reported to stockholders. Capital, K, was approximated by the value of gross plant, representing tangible fixed property such as land, buildings, and equipment, deflated by an implicit price index for nonresidential gross private investments (Bureau of Economic Analysis). The average share of labor in total sales, b, over the period 1975–1979 was estimated as the total labor expenditures of the firm in 1977 per unit of 1977 sales. For those firms not reporting labor-related expenditures to Compustat, labor's share was computed by using the product of the average 1977 annual wage in each firm's industry (Bureau of the Census, 1977) and the total number of 1977 employees in the firm. The average share of capital is $(1 - b)$. Then, TFP was measured as the slope coefficient from a regression of g_t on trend for each firm (Mansfield, 1980).

The variable RD is measured in several ways. First it is measured as the firm's 1977 total R&D expenditures as reported to Compustat. Then RD is dichotomized into the

[5] For a more detailed derivation of the model, see either Griliches (1980a) or Link (1980). For a partial review of other studies see Griliches (1979).

portion of R&D allocated to activities to comply with environmentally related government regulations, RD_E, and the part devoted to maintain the firm's "traditional" types of innovative activities, RD_T. Data on the allocation of each firm's R&D expenditure on activities designed to comply with environmentally related government regulations were obtained by survey. The survey population was the 155 manufacturing firms in the chemicals (49), machinery (80), motor vehicles (7), and petroleum industries (19) reported by *Business Week* (1980). Firms in these industries are the most active in environmentally related R&D. The motor vehicle industry was eliminated because of a poor response rate.[6] The 97 participating firms represent a survey response rate of 65.5%. These firms conduct 64.0% of all R&D expenditures in the three reporting industries: the specific R&D coverage ratios are 74.6% for chemicals, 59.4% for machinery, and 49.3% for the petroleum industry. The survey percentages on environmental R&D were imputed to each firm's total R&D expenditures to calculate RD_E and RD_T.

Following others (Terleckyj, 1974; Mansfield, 1980; Link, 1981b), I included an index of industry unionization U in the estimating version of equation (4). Specifically, I included the percentage of workers unionized in the three-digit SIC industry in which the firm performs its main operations (Freeman and Medoff, 1979).[7]

Descriptive statistics associated with the calculated values used in the estimation are reported in Table 2.[8]

The least-squares results, with t-statistics in parentheses, are shown in equations (5) and (6):

$$TFP = \underset{(2.51)}{.067} + \underset{(1.67)}{.312}(RD/Y) - \underset{(1.98)}{.103}U \qquad R^2 = .337 \tag{5}$$

and

$$TFP = \underset{(3.01)}{.062} - \underset{(1.72)}{1.22}(RD_E/Y) + \underset{(2.87)}{.538}(RD_T/Y) - \underset{(1.90)}{.092}U \qquad R^2 = .389. \tag{6}$$

The result reported in equation (5) suggests that the relationship between R&D and

TABLE 2 Descriptive Statistics Related to the Primary Data

	TFP		*Y* (millions $)		*RD/Y*		RD_E/Y		RD_T/Y	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Survey Sample, $n = 97$:	.039	.05	$1835	$3034	1.8%	1.2%	.16%	.15%	1.7%	1.2%
Chemicals, $n = 32$:	.055	.04	$1763	$2160	2.2%	1.2%	.21%	.18%	1.9%	1.1%
Machinery, $n = 51$:	.035	.04	$571	$1172	2.0%	1.0%	.15%	.09%	1.8%	.95%
Petroleum, $n = 14$:	.023	.06	$6604	$4726	.41%	.35%	.09%	.08%	.32%	.31%

[6] Only one firm in this industry was willing to provide the requested information.

[7] Kendrick (1973) suggests that the impact of unionization is ambiguous. On the one hand, work rules or efforts to thwart innovation by some unions could lower productivity if employment levels are threatened. On the other hand, if wages are significantly higher in certain unionized industries, firms may induce labor-saving technologies that could raise measured productivity. Most researchers have found the net effect to be negative.

[8] To preserve the confidentiality of those firms which participated in my survey, maximum and minimum values are not given. It can be reported, however, that the range of values of the survey percentages of R&D allocated to environmentally related activities is 3%–20% (mean is 9.7%) for chemicals, 1%–9% (mean is 4.8%) for machinery, and 6%–40% (mean is 23.7%) for the petroleum industry.

TABLE 3 **Estimated R&D Coefficients, by Industry (t-statistics in parentheses)**

	Independent Variables		
Industry	(1) (RD/Y)	(2) (RD_E/Y)	(3) (RD_T/Y)
Chemicals:	.512	−.583	.912
	(2.16)	(1.90)	(3.65)
Machinery:	.337	−1.01	.625
	(1.19)	(1.27)	(2.13)
Petroleum:	.205	−2.36	.241
	(1.31)	(1.73)	(1.89)

measured productivity growth is positive, but weak. The estimated coefficient on (RD/Y) is significant only at the .05 level (one-tailed test).[9] This empirical result is consistent with the findings of others that the contribution of RD to measured productivity growth during the 1970s was tenuous. But when RD is dichotomized into the components RD_E and RD_T, in equation (6), the estimated coefficient on RD_T is positive and significant at the .01 level (one-tailed test): the estimated coefficient on RD_E is negative and significant at the .10 level (two-tailed test).[10]

The opportunities for R&D-related breakthroughs might be intrinsically richer in certain industries than in others. This possibility was considered by including dummy variables, interacted with the R&D variables, into specifications (5) and (6). Those results are summarized in Table 3. The findings reported in column (1) correspond to those in equation (5) with separate slope coefficients on (RD/Y) for each industry grouping. Each

[9] Since the regression coefficient on (RD_T/Y) theoretically corresponds to the marginal product of the firm's technical capital, a negative coefficient seems implausible. Therefore, a one-tailed hypothesis test was performed. In equation (6), however, a two-tailed test was performed on (RD_E/Y), since the marginal social benefits from environmental compliance may not be (and probably are not) fully measured in TFP.

[10] Unfortunately, there are no other studies with which to compare these results. In an attempt to evaluate the generality of the results reported in equation (6), a similar analysis was carried out by using manufacturing data for 14 two-digit SIC industries. TFP was measured as the average annual rate of growth in total factor productivity between 1970 and 1976, as reported by Kendrick and Grossman (1980). Total industry R&D expenditures for 1974 came from the McGraw-Hill (1976) annual survey; industry net sales for 1974 came from the National Science Foundation (1979); and the portion of industry 1974 R&D allocated to meeting pollution abatement requirements came from McGraw-Hill (1975). The regression coefficient on (RD_E/Y) was −6.14 (significant at the .20 level) and on (RD_T/Y) it was .44 (significant at the .01 level).

Although the regression specification underlying the results reported in equation (6) accounts for one aspect of the heterogeneity of R&D, the activities measured as RD_T are themselves varied. As Mansfield (1980) noted, those activities broadly grouped under the rubric of R&D are very diverse. Basic research represents original investigation for advancing scientific knowledge which does not have a specific commercial objective, whereas development is technical activity concerned with nonroutine problems in translating research findings into products or processes. Accordingly, the variable RD_T is further disaggregated into expenditures for basic research, B_T, and for applied research and development, $(A + D)_T$. These data were also gathered in the survey. The least-squares results are:

$$\underset{(3.17)}{TFP = .059} - \underset{(1.83)}{1.09}(RD_E/Y) + \underset{(3.96)}{2.61}(B_T/Y) + \underset{(2.51)}{.317}((A + D)_T/Y) - \underset{(1.91)}{.086}U \qquad R^2 = .428.$$

The basic-applied plus development dichotomy is also statistically important, as others have found (Mansfield, 1980; Link, 1981a). B_T has the largest impact on TFP of all the R&D-related variables. Data were also gathered on the average annual growth rate in the percentage of R&D allocated toward environmental compliance from 1977 through 1980. The annual industry averages are 61.5% in chemicals, 23.2% in machinery, and 70.7% in the petroleum industry. Firms also reported that most of these funds were allocated at the expense of applied R&D activities. The percentage of environmentally related R&D that would have gone to basic research was 4.1% in chemicals, 1.6% in machinery, and .8% in the petroleum industry.

estimated coefficient is positive, but only that for the chemicals industry is statistically significant (at the .01 level). The results in columns (2) and (3) are analogous to those in equation (6): the estimated coefficients on (RD_T/Y) are all positive, but the level of significance varies: chemicals, .01 level; machinery, .05 level; petroleum, .10 level. As in equation (6), each of the estimated coefficients on (RD_E/Y) is negative, but only the coefficient corresponding to the chemicals industry is significant (.10 level).[11]

There appear to be marked interindustry differences in the magnitude of the statistical relationship between R&D and measured productivity growth. The estimated coefficients on (RD/Y) and (RD_T/Y) are largest in the chemicals industry and smallest in the petroleum industry; the estimated coefficient on (RD_E/Y) is smallest in the chemicals industry and largest in the petroleum industry. This result is consistent with the survey finding that the percentage of environmentally related compliance costs that are covered by R&D activities is, on average, 10.8% in the chemicals, 17.9% in machinery, and 23.1% in the petroleum industry.

3. Conclusions

■ The results reported in equations (5) and (6) and in Table 3 illustrate that a portion of R&D, even in the 1970s, was an important contributor to measured productivity growth. This fact is statistically lost by the failure to disaggregate R&D. In addition, the results suggest that R&D activities directed toward meeting environmental regulations may even be reducing the growth of measured productivity, *ceteris paribus*.[12] Denison (1978), for example, estimated that policy-induced environmental expenditures slowed the annual growth of labor productivity by .05 percentage points from 1967 to 1969, by .10 percentage points from 1969 to 1973, and by .22 percentage points from 1973 to 1975.[13]

The model underlying this analysis is quite simple, and the empirical analysis is based on only a small sample of manufacturing firms. Until more detailed studies are conducted regarding the various uses of R&D and the lags associated with the impact of each category on productivity growth, these findings should be viewed as preliminary.

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[11] A series of F-tests was conducted to determine whether the structure of the estimated equations differs among industries. The null hypothesis of equality of coefficients across industries (equation (6)) was rejected at the .01 level ($F_{4,88} = 7.27$) in favor of the specifications reported in columns (2) and (3) of Table 3. Also, pairwise F-tests were conducted for the three industry groups. The null hypothesis of equality of coefficients between the chemicals and machinery industry was rejected at the .01 level ($F_{2,80} = 21.79$); between the chemicals and petroleum industries the null hypothesis was rejected at the .01 level ($F_{2,40} = 10.61$); but between the machinery and petroleum industries the null hypothesis was accepted ($F_{2,59} = 2.71$).

[12] This does not imply that firms operate with a fixed R&D budget and that the more of it they allocate to RD_E, the less there is available for RD_T. Clearly, firms will allocate to RD_E the amount of funds necessary to comply with environmental regulations, and then they will reallocate their investment dollars (RD_T being one category) until expected marginal returns, adjusted for risks, are equalized. In the specification of equation (6), variation in (RD_T/Y) can be interpreted as the firms' deliberate attempts to vary the RD_T budget until the marginal product of RD_T equals its marginal cost, holding constant expenditures on RD_E.

[13] It is also estimated by Denison (1979) that after 1975, the impact dropped to .08 percentage points. Norsworthy, Harper, and Kunze (1979) also estimate that the effect of pollution abatement equipment costs has a negative effect on productivity: .03 percentage points from 1948–1965, .09 percentage points from 1965–1973, and .19 percentage points from 1973–1978. Finally, Christainsen and Haveman's (1981) research suggests that federal regulations *per se* are responsible for 12 to 21% of the slowdown in growth of labor productivity in U.S. manufacturing during 1973–1977 as compared with 1958–1965. Of course, any benefit-cost analysis of environmental regulations must consider the externalities at which such regulations were aimed. That was not the intent of this article.

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