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Chapter Author: Nestor Terleckyj

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III. The Effects of Research and Development, Energy, and Environment on Productivity Growth

6 Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries

Nestor E. Terleckyj

6.1 Introduction

In an earlier study by the author, rather high estimates were obtained of the effects of industrial R and D on the rate of productivity growth of industries (Terleckyj 1974). Two kinds of such effects were identified using the total factor productivity data compiled by John W. Kendrick (1973): direct effects in the industries in which the R and D is conducted, and indirect effects in the industries purchasing intermediate and capital inputs from the industries conducting the R and D. Indications of presence of these effects were obtained for the privately financed R and D, but not for government financed R and D, and for the manufacturing industries but not for the nonmanufacturing industries. Because human capital was not included in earlier research, the resulting estimates of productivity returns to R and D might be inflated by the possible effects of increases in the employment of human capital if such increases were correlated with increased use of R and D inputs.

In this paper these results are tested for independence from possible effects of increased use of human capital and other input characteristics, first by introduction of an explicit variable measuring increases in the use of human capital by industry and then by repeating estimation of the R and D effects using the measures of total factor productivity

Nestor E. Terleckyj is with the National Planning Association.

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growth prepared by Gollop and Jorgenson (1979) which are already adjusted for the use of human capital, as well as for other characteristics of input.

6.2 The Analytical Model

The theoretical model underlying the present analysis treats the research capital as a third input in addition to the labor and capital inputs. This model has been formulated by Griliches (1973). Its adaptation to the present analysis has been discussed in earlier work by the author (Terleckyj 1974, pp. 3–8, 19). Hence, only a very brief discussion of the model will be provided here.

In this model the production function for time, t, is represented by:

$$(1) \qquad Q = Ae^{\lambda t} L^{\beta} K^{(1-\beta)} R^{\alpha},$$

where Q, L, K, and R are the output, and the inputs of labor, tangible capital, and R and D capital, respectively; β, $(1-\beta)$, and α are the respective elasticity parameters for the three inputs; A is a constant specifying the level of output in the base year; and the parameter λ represents the disembodied growth of productivity.

The productivity ratio at time t can then be expressed as a product of a component representing cumulative effects of disembodied technical change and the stock of R and D capital raised to an exponent representing the elasticity of output with respect to research capital:

$$(2) \qquad P_t = \frac{Q_t}{L^{\beta}{}_t K^{(1-\beta)}{}_t} = Ae^{\lambda t} R^{\alpha}{}_t.$$

Differentiating this equation with respect to time, one can show that the rate of growth in productivity is the sum of the autonomous disembodied component and a component representing the product of the relative growth of research capital and the elasticity of output with respect to that capital:

$$(3) \qquad p = \frac{\dot{P}}{P} = \lambda + \alpha \frac{\dot{R}}{R}.$$

Because the rate of growth of research capital usually cannot be directly observed, an alternative formulation of equation (3) may be used, provided one assumes that the gross investment in R and D, i.e., the expenditure for R and D in the base year, also represents the net R and D investment (i.e., that there is no depreciation of R and D or that it can be ignored). One can then express the second term on the right-hand side of equation (3) by a product of the marginal product of capital, v, and the ratio of R and D investment to output, I:

$$(4) \qquad p = \lambda + vI,$$

(because $v = dQ/dR$, $I = \dot{R}/Q$, and $\alpha = dQ/dR \cdot R/Q$, $\alpha\dot{R}/R = vI$).

The present research results are based on the statistical estimates of an expanded version of equation (4). The equation is expanded by introducing successively different components of research investment: first, by separating R and D conducted in industry according to its source of financing—into the cost of research conducted with private funds of the industry and research conducted with the federal government funds—and then by estimating the R and D embodied in purchases from other industries separately for the privately financed and the government-financed R and D. The equation is also expanded by the introduction of variables other than R and D which have been found to be correlated with productivity growth and the omission of which might distort estimates of the net effect of R and D on productivity. The general form of the equations estimated in this study can be stated as follows:

$$p = a_0 + \sum_i a_i X_i + \sum_j b_j I_j. \tag{5}$$

Here a_0 is the constant of regression representing (when normalized) the remaining unexplained residual growth. The a_i's are the regression coefficients of the variables X_i, which represent factors other than R and D, and the b_j's are the coefficients of the research intensity ratios, I_j's.

The coefficients b_j are the estimates of the marginal products of the respective types of R and D capital. They also represent the productivity rates of return on the different types of R and D expenditures. Because the costs of labor and of capital used in R and D are already included in the input index used to estimate productivity, the regression coefficients b_j measure the "excess" or additional rates of return to R and D, i.e., net of its cost. Thus, the statistical estimates of the productivity rates of return approximate the concept of "internal rates of return." The accuracy of this statistical approximation actually achieved depends among other things on the extent to which the cost and the effects of *same* R and D projects are included in the data for the period used. The period 1948–66 used in the present analysis covers 18 years. It should be sufficient to include a predominance of complete lifetimes of R and D projects and their productivity effects. The time series data on costs and on private and social returns to innovations developed by Mansfield and his associates in their case studies of specific innovations support this assumption (Mansfield et al. 1975).

6.3 Previous Estimates

In the following discussion, only the main results and the basic data of previous research are summarized. The methods of estimation of data, various qualifications, and details regarding specific assumptions were discussed in the publication in which these results were first given (Terleckyj 1974).

The basic data are shown in tables 6.1 and 6.2. Kendrick's (1973, pp. 78, 79) data for the rates of change in total factor productivity for the period 1948–66 which were used as the dependent variable, are shown in table 6.1 together with the author's estimates of the four R and D investment intensity ratios for the base year 1958. Estimates of R and D embodied in purchased goods were derived by summing the R and D of the conducting industries, redistributed in proportion to their sales as given in the 1958 Department of Commerce input-output matrices for intermediate and capital flows among industries. Table 6.2 contains the data for the three non–R and D variables introduced to hold productivity effects of R and D constant. One of these variables is the percent of sales to the private sector, which tends to have positive effects on productivity. Another is the unionization rate of the work force of the industry. It was found by Kendrick (1973) to have significant negative correlation with productivity growth. It is also included here for a different year (1953 rather than 1958, because nonmanufacturing data could not be obtained for 1958). The third variable is an index of cyclical instability of output of the industry which in another study by the present author was found to have a negative effect on productivity (Terleckyj 1960).

The highlights of the results obtained are shown in table 6.3, which contains a series of estimates of equation (5) for twenty manufacturing industries. The table follows the sequence of analysis of the R and D variables. First, the total ratio for all R and D conducted in the industry was introduced. Its coefficient was not statistically significant at the 5% level. After dividing the total R and D into privately financed and government-financed R and D, the estimated rate of productivity return to private R and D was highly significant and amounted to 37%, while the return estimated for the government-financed R and D was not significant (and numerically near zero). Based on this result, the ratio of government-financed R and D was omitted from further analyses, and the total R and D embodied in purchases from other industries was introduced. The coefficient for industry's own R and D continued to be significant, but its magnitude dropped from 37 to 28%. The estimate of return to total imputed R and D was 45% and significant at the 5% level. External R and D was then divided into government-financed and privately financed components. This division of the embodied R and D resulted in an overall improvement in the fit of the equation and increases in the significance of almost all coefficients but one (sales not to government). The coefficient obtained for privately financed R and D embodied in purchased inputs is equivalent to a 78% rate of productivity return, while the coefficient estimated for the government-financed purchased R and D is near zero, negative, and not significant.

Table 6.1 **Rates of Growth in Total Factor Productivity, 1948–66, and the 1958 R and D Value Added Ratios for Privately Financed R and D and for Government Financed R and D Conducted in the Industry and for Privately Financed and Government Financed R and D Embodied in Purchased Goods, Thirty-three Industries in the Private Domestic Economy (R and D amounts as percent of value added)**

Industry (arranged in order of descending productivity growth)	Productivity Growth Rate, Annual Average 1948–66 (percent)	R and D Intensity Ratios, 1958: R and D Conducted in Industry: Privately Financed R and D (percent)	R and D Conducted in Industry: Government Financed R and D (percent)	R and D Embodied in Purchased Goods: Privately Financed R and D (percent)	R and D Embodied in Purchased Goods: Government Financed R and D (percent)
*Air transportation	8.0	0	0	1.6	1.5
*Coal mining	5.2	0	0	.3	.1
*Railroads	5.2	0	0	.2	.1
Chemicals	4.9	6.8	1.8	1.8	.8
*Electric and gas utilities	4.9	.1	0	.3	.3
Textiles	4.0	.4	0	2.1	.1
Rubber products	3.9	1.1	.4	2.3	.3
*Communication utilities	3.8	.3	.1	.6	1.1
Electrical machinery	3.7	5.5	12.0	1.9	3.3
Lumber products	3.5	.2	0	.3	.1
*Farming	3.3	.5	0	.6	.1
*Oil and gas extraction	3.2	.2	0	.1	.1
Transportation equipment and ordnance	3.2	6.9	18.6	3.8	3.8
Foods	3.0	.5	0	.6	.1
Petroleum refining	3.0	4.3	.2	.9	.3
Furniture	2.9	.2	0	.4	.1
Instruments	2.9	4.2	3.6	2.1	2.2

Table 6.1 (cont.)

Industry (arranged in order of descending productivity growth)	Productivity Growth Rate, Annual Average 1948–66 (percent)	R and D Intensity Ratios, 1958			
		R and D Conducted in Industry		R and D Embodied in Purchased Goods	
		Privately Financed R and D (percent)	Government Financed R and D (percent)	Privately Financed R and D (percent)	Government Financed R and D (percent)
Printing and publishing	2.7	0	0	.2	.2
Machinery, excluding electrical	2.6	3.7	2.5	1.1	.9
*Nonmetal mining	2.6	0	0	.4	.1
Paper	2.5	.9	0	.5	.1
*Wholesale trade	2.5	0	0	.1	.1
*Metal mining	2.4	0	0	.4	.2
*Retail trade	2.4	0	0	.1	.1
Stone, clay, and glass products	2.4	.9	0	.5	.1
Beverages	2.2	0	0	.6	.1
Apparel	1.9	.1	0	.3	0
Fabricated metal products	1.9	.7	.5	.7	.3
Leather Products	1.7	.2	0	.2	.1
Primary metal products	1.6	.9	.1	.6	.2
*Contract construction	1.5	0	0	.6	.3
Tobacco products	1.1	0	0	.3	0
*Water transportation	0.5	0	0	.4	0

*Nonmanufacturing industries.

SOURCES: Productivity Growth Rate data reproduced by permission from the author: Kendrick (1973) table 5-1, pp. 78–79; R and D intensity ratios from Terleckyj (1974), pp. 13, 15. Note revision of data for beverages industry R & D conducted in industry ratios.

Table 6.2 **Variables Other than R and D Tested for Possible Effects on Productivity Growth, Thirty-three Industries in the Private Domestic Economy**

Industry (arranged in order of descending productivity growth)	Sales Other than to Government as Percent of Total Sales 1958 PVTS (percent)	Union Members as Percent of All Workers in Producing Establishments 1953 UN (percent)	Index of Cyclical Instability of Industry Output 1948–66 CYC (percent)
*Air transportation	95	51	0
*Coal mining	98	84	16.1
*Railroads	95	95	10.4
Chemicals	95	39	5.7
*Electric and gas utilities	96	41	0
Textiles	100	30	7.4
Rubber products	97	54	9.5
*Communication utilities	97	52	0
Electrical machinery	90	56	11.0
Lumber products	100	21	8.7
*Farming	98	1	3.2
*Oil and gas extraction	100	14	5.4
Transportation equipment and ordnance	77	65	11.0
Foods	100	45	0
Petroleum refining	94	67	2.5
Furniture	95	29	8.7
Instruments	85	50	9.2
Printing and publishing	98	38	3.2
Machinery, excluding electrical	95	45	13.1
*Nonmetal mining	99	32	4.6

Table 6.2 (cont.)

Industry (arranged in orders of descending productivity growth)	Sales Other than to Government as Percent of Total Sales 1958 PVTS (percent)	Union Members as Percent of All Workers in Producing Establishments 1953 UN (percent)	Index of Cyclical Instability of Industry Output 1948–66 CYC (percent)
Paper	99	45	6.7
*Wholesale trade	99	4	4.1
*Metal mining	92	70	10.6
*Retail trade	99	14	3.6
Stone, clay and glass products	100	45	7.4
Beverages	100	44	3.2
Apparel	99	53	4.1
Fabricated metal products	99	45	8.4
Leather products	99	39	5.0
Primary metal products	98	55	15.2
*Contract construction	71	72	4.1
Tobacco products	100	58	2.0
*Water transportation	95	76	7.0

*Nonmanufacturing industries.

SOURCES: Data on industry sales to government is from U.S. Department of Commerce, Office of Business Economics, "The Transactions Table of the 1958 Input-Output Study and Revised Direct and Total Requirements Data," *Survey of Current Business*, 9 (1965): 34–39; percent unionization is from H.G. Lewis, *Unionization and Wages in the United States* (Chicago: University of Chicago Press, 1963), pp. 289–290; cyclical instability index of industry output is based on annual output data from Kendrick (1973) calculated in a manner described in Terleckyj (1960). See note 6, p. 16, in Terleckyj (1974).

Table 6.3 **Regression Coefficients Obtained in the Analysis of the Annual Rates of Change in Total Factor Productivity for the Period 1948–66, Twenty Manufacturing Industries (*t*–ratios in parentheses)**

	Cost of R and D/Value-added Ratios for Different R and D Components									
	R and D Conducted in Industry			R and D Embodied in Purchases from Other Industries			Other Variables			
Constant of Regression	Total, 1958	Privately Financed, 1958	Government Financed, 1958	Total, 1958	Privately Financed, 1958	Government Financed, 1958	Percent of Sales Not to Government, 1958	Union Members as Percent of Workers in Producing Establishments, 1953	Annual Rate of Cyclical Change in Output, 1948–66	R^2 Corrected
a_0	IRDI	IRDN	IRDG	PRDI	PRDN	PRDG	PVTS	UN	CYC	
2.29 (0.31)	0.12 (1.76)						0.02 (0.33)	−0.04 (2.38)	−0.03 (0.56)	0.39
1.62 (0.25)		0.37 (3.31)	0.01 (0.12)				0.03 (0.46)	−0.05 (2.94)	−0.03 (0.56)	0.44
−7.83 (1.36)		0.28 (2.84)		0.45 (2.49)			0.12 (2.20)	−0.05 (3.54)	−0.05 (1.25)	0.62
−3.72 (0.71)		0.29 (3.43)			0.78 (3.79)	−0.09 (0.34)	0.08 (1.54)	−0.05 (4.03)	−0.04 (1.30)	0.72

SOURCE: Terleckyj (1974), pp. 20, 22, 26, 29.

The effects estimated for the three non–R and D variables remained rather stable, in the course of these substitutions of the R and D variables.

These results for the manufacturing industries constituted the main findings of the earlier study. The results for nonmanufacturing (not reproduced here) were rather erratic. No indication of positive returns to R and D conducted in the industry was obtained. But, for this group of industries, it is not surprising. It may simply reflect the fact that most nonmanufacturing industries conduct little or no R and D. (Also, the R and D data for the nonmanufacturing industries were derived from the NSF data by a series of additional assumptions.) On the other hand, a statistically significant coefficient was obtained for indirect returns, suggesting a very high rate of productivity return of 187%. Dividing the indirect R and D by sources of financing gave large and positive coefficients for both components which, however, were not statistically significant.

The overall fit of the equation for all industries combined was consistently lower than for either manufacturing or nonmanufacturing industries alone. Among the coefficients for the R and D intensity ratios, only the one for the total R and D cost embodied in purchases was statistically significant.

6.4 Productivity Returns to R and D with Consideration of Human Capital

Human capital is not included in the measures of input used in estimating productivity growth. The underlying indexes of labor input used in constructing the indexes of total factor productivity from which the growth data are derived are based on the number of man-hours. Consequently, a part of growth in productivity may represent productivity returns to a growing stock of human capital. Moreover, if increases in the use of human capital are correlated with increased use of R and D capital, the regression coefficients intended to measure the productivity return to R and D may be biased upward to the extent that they (also) reflect returns to human capital. Use of human capital may be correlated either with own R and D, if use of human capital in production is complementary with the conduct of R and D, or with purchased R and D, if human capital is complementary with the use of R and D–intensive, "high-technology" inputs. Thus, the regression coefficients for both direct and indirect return to R and D are subject to potential bias from this source.

In testing the hypothesis that the previously obtained statistical estimates of returns to R and D do not include the returns to human capital as well, the estimating equations are revised to include human capital investment intensity as an additional variable. This variable is formulated in the same manner as the R and D investment intensity variable. After the introduction of human capital, equations (2), (3), and (4) discussed earlier become equations (6), (7), and (8):

$$P_t = Ae^{\lambda t}R^{\alpha}{}_{t}H^{\gamma}{}_{t}, \tag{6}$$

$$p = \frac{\dot{P}}{P} = \lambda + \alpha\frac{\dot{R}}{R} + \gamma\frac{\dot{H}}{H}, \tag{7}$$

$$p = \lambda + v\frac{\dot{R}}{Q} + r\frac{\dot{H}}{Q}. \tag{8}$$

Here γ is the elasticity parameter, analogous to α, and r in equation (8) is the productivity rate of return to human capital, analogous to v for research capital. Both parameters are estimated as regression coefficients of the respective net investment intensity ratios in the estimating equation for productivity growth. However, while the basic cost of R and D activities conducted in an industry is included in the labor and capital input indexes (except for the effect of differences in labor cost per man-hour), the cost of human capital is not included in the input data.

No direct measures of human capital stock or investment exist that could be readily applied in estimating its productivity effects. Human capital has to be measured indirectly, by schooling or by an indicator of its market value. In this paper, the indicator of human capital is investment intensity. It is based on the increases in real wages per man-hour worked.

This indicator of growth of human capital is based on its evident market value. The advantage of basing the measure of human capital on wages rather than on schooling is that such a measure includes both schooling and experience components of earning power (Mincer 1974), which presumably reflects productivity and at the same time excludes consumption components of schooling and the variability of the learning content of years of schooling over time. However, there are also disadvantages in using the relative real wage growth as a measure of human capital investment. One is that other factors unrelated to worker productivity affect this growth to an unknown extent. Such factors as wage bargaining or legislation have autonomous effects on wages.

Also, because, statistically, the growth in labor compensation is a major component of growth in output and output per man-hour is by definition a large part of the total factor productivity growth, the human capital investment rate estimated from growth in real wages is subject to some possibility of the simultaneous equation bias. However, this bias would not arise if the competitive working of the labor market equalized the earnings within occupations rapidly relative to the length of time over which the productivity growth is measured. Then the observed long-term increases in wages in the individual industries would be independent of the increases in productivity in the same industries because the period of observation would be sufficiently long for the correlation to reflect only the effects of increases in human capital on productivity.

The best approach to resolve the uncertainties resulting from the nature of the indicator used for human capital is to test the results obtained by alternative indicators. Use of alternative indicators was not possible within the scope of this paper because of the lack of the available data in comparable industry detail or for the period studied. It should be possible in future research to develop or adapt indicators of average education and of the skill mix of labor input in individual industries. Here, a more general further test of independence of the estimated effects of R and D from previously unmeasured inputs is undertaken by estimating the effects of industrial R and D on the total factor productivity growth measured after an adjustment for human capital and other inputs.

The real wage growth was calculated from unpublished NBER data used in Kendrick's study. The original data were in the form of period averages of actual hourly earnings for the period 1948–53 and again for the period 1960–66. These averages were converted to 1958 dollars by the Consumer Price Index. The difference between the two period averages was divided by 12.5, the number of years between the midpoints of the two periods. The result is shown in the first column in table 6.4. Equation (8) requires the net rate of investment in human capital in the aggregate in the industry rather than per hour. Therefore, the amount per hour in the first column is multiplied by the man-hours worked in the industry in the base year, 1958, used in this study. The result, giving the investment in human capital in millions of 1958 dollars, is shown in the second column. This result is then divided by the 1958 value added by industry in order to obtain the desired variable, $\dot{H}/Q$, i.e., the human capital investment intensity ratio which is shown in percentages in the third column.

It may be noted that, while, theoretically, human capital investment intensity ratios are commensurate with the R and D investment intensity ratios used in the regression analysis, statistically their estimates are much stronger. The human capital data are actually based on change for the entire period rather than on the experience in the base year. Also, they are based on net investment in human capital rather than on the gross investment as was the R and D ratio.

The results of introducing human capital investment into the estimating equation for productivity growth for the twenty manufacturing industries are given in table 6.5. The estimated effect of the human capital

Table 6.4 **Estimates of the Net Investment Rate in Human Capital, Thirty-three Manufacturing and Nonmanufacturing Industries, 1958 (dollar amounts in 1958 dollars)**

Industry (listed in order of descending rate of productivity growth)	Average Annual Increase in Real Wage per Hour Worked, 1948–66 (1)	Estimated Industry Investment[a] 1958 (millions) (2)	Industry Investment as Percent of Value Added, 1958 (3)
*Air transportation	$.1015	$ 36.5	2.4%
*Coal mining	.0711	27.6	1.6
*Railroads	.1112	216.4	2.6
Chemicals	.1080	172.7	1.9
*Electric and gas utilities	.0952	127.4	1.2
Textiles	.0340	60.9	1.5
Rubber products	.0678	46.2	1.6
*Communications	.0817	141.2	1.6
Electrical machinery	.0751	182.2	2.0
Lumber products	.0503	67.9	2.1
*Farming	.0166	208.8	1.0
*Oil and gas extraction	.0591	44.5	.5
Transportation equipment and ordnance	.1171	414.4	2.6
Foods	.0743	235.2	1.9
Petroleum refining	.1430	63.5	2.0
Furniture	.0477	36.2	1.9
Instruments	.0917	59.4	2.3
Printing and publishing	.0433	77.1	1.3
Machinery, excluding electrical	.0847	232.6	2.1
*Nonmetal mining	.0695	19.3	1.9

Table 6.4 (cont.)

Industry (arranged in order of descending productivity growth)	Average Annual Increase in Real Wage per Hour Worked, 1948–66 (1)	Estimated Industry Invesment[a] 1958 (millions) (2)	Industry Investment as Percent of Value Added, 1958 (3)
Paper	.0769	89.5	1.9
*Wholesale trade	.0706	468.7	1.6
*Metal mining	.0800	15.3	1.4
*Retail trade	.0415	892.4	2.0
Stone, clay, and glass products	.0812	93.4	2.0
Beverages	.0569	23.8	1.0
Apparel	.0284	60.0	1.3
Fabricated metal products	.0736	159.6	2.0
Leather products	.0369	24.1	1.6
Primary metal products	.1142	250.7	2.3
*Contract construction	.0858	607.6	3.0
Tobacco products	.0907	16.2	.6
*Water transportation	.0455	43.0	2.9

*Nonmanufacturing industries.
[a]Average annual increase in real wages per hour worked from column (1) multipled by the number of man-hours worked in 1958, as
SOURCES: John W. Kendrick and the National Bureau of Economic given in Kendrick (1973), pp. 196–97.
Research, unpublished data on real wages.

Table 6.5 **Regression Coefficients Obtained in the Analysis of the Annual Rates of Change in Total Factor Productivity for the Period 1948–66 with Additional Variables, Twenty Manufacturing Industries (t-ratios in parentheses)**

	Cost of R and D/Value-added Ratios for Different R and D Components				Other Variables				
	R and D Conducted in Industry		R and D Embodied in Purchases from Other Industries						
Constant of Regression	Privately Financed, 1958	Government Financed, 1958	Privately Financed, 1958	Government Financed, 1958	Percent of Sales Not to Government, 1958	Union Members as Percent of Workers in Producing Establishments, 1953	Annual Rate of Cyclical Change in Output, 1948–66	Human Capital Investment Intensity Ratio Based on Growth of Real Wages 1958	R^2 Corrected
a_0	IRDN	IRDG	PRDN	PRDG	PVTS	UN	CYC	HCIW	
−6.58 (1.53)	.25 (3.00)		.82 (3.99)		.10 (2.62)	−.04 (3.38)	−.07 (1.73)	.39 (1.04)	.73
−6.17 (1.02)	.25 (2.50)	−.05 (.59)	.85 (3.78)	.17 (.37)	.10 (1.70)	−.04 (3.41)	−.07 (1.56)	.38 (.93)	.69

variable is not statistically significant, while, on the whole, the previous results remain unaffected by its introduction.

6.5 Results with Productivity Data Based on an Inclusive Concept of Input

In their paper, Gollop and Jorgenson have developed a set of estimates of output, input, and total factor productivity for individual industries (as well as economic sectors and the economy) which are based on different measurement concepts than the estimates by Kendrick, which are used to derive the estimates of the effects of R and D on productivity. Thus, while Kendrick measures the net output and the net input, Gollop and Jorgenson use gross measures of output and input, i.e., including intermediate inputs.

Also, the Gollop-Jorgenson method attempts to account for quality characteristics of inputs, and their input index accordingly includes "quality" index components for labor and for capital.

To the extent that research and development activities result in improved intermediate and capital inputs, one would expect the estimates of productivity rates of returns to R and D to be lower when productivity is derived from the input data already adjusted for the quality changes than when the calculation of productivity growth is based on the unadjusted inputs.

The two sets of productivity data also differ in the underlying theoretical formula. Kendrick implicitly used a reduced form of the Cobb-Douglas production function. The Gollop-Jorgenson data are derived from a translog production function. The two sets of productivity estimates also differ in the method of estimating the man-hours input and in the estimate of depreciation of physical capital. But in contrast to the input quality adjustments, there is no apparent reason to expect these differences in measurement to have a systematic effect on the observed correlations between productivity growth and the R and D variables.

The results of substituting Gollop-Jorgenson estimates for Kendrick estimates of productivity change[1] for the twenty manufacturing industries and with the same independent variables are shown in table 6.6. The Gollop-Jorgenson estimates are not available for the nonmanufacturing industries.

1. With two minor changes in the Gollop-Jorgenson data to make consistent the industry definitions: (1) Productivity growth for "food and kindred products" is used for both "food products" and "beverages," and (2) the arithmetic average of growth rates for "motor vehicles" and for "transportation equipment, other than motor vehicles, and ordnance" was used for "Transportation equipment and ordnance."

Table 6.6 **Regression Coefficients Obtained with Alternative Estimates of the Anuual Rates of Change in Total Factor Productivity, Twenty Manufacturing Industries, 1948–66 (*t*-ratios in parentheses)**

		Cost of R and D/Value-added Ratios for Different R and D Components				Other Variables			
		R and D Conducted in Industry		R and D Embodied in Purchases from Other Industries					
	Constant of Regression	Privately Financed, 1958	Government Financed, 1958	Privately Financed, 1958	Government Financed, 1958	Percent of Sales Not to Government, 1958	Union Members as Percent of Workers in Producing Establishments, 1953	Annual Rate of Cyclical Change in Output, 1948–66	R^2 Corrected
	a_0	IRDN	IRDG	PRDN	PRDG	PVTS	UN	CYC	
Kendrick data	−4.01 (.73)	.27 (2.92)	−.05 (.53)	.81 (3.66)	.12 (.26)	.08 (1.52)	−.04 (3.69)	−.05 (1.37)	.69
Gollop-Jorgenson data	−32.26 (1.79)	.20 (.64)	−.18 (.63)	1.83 (2.53)	1.67 (1.10)	.33 (1.87)	−.03 (.88)	−.02 (.14)	.30

Compared to the estimates based on Kendrick's data, the estimates derived with the Gollop-Jorgenson data in table 6.6 have a much poorer statistical fit. But the two sets of estimates are qualitatively consistent. The signs of all coefficients are the same in both equations, and their general magnitudes are comparable. Among the four R and D variables, only the coefficient for privately financed purchased R and D is statistically significant at the 5% level. It is also considerably larger (1.83) than the coefficient derived with the Kendrick data (0.81), despite the much lower estimates of productivity growth by Gollop-Jorgenson (averaging 0.9% a year for the twenty manufacturing industries during the period 1948–66) than by Kendrick (averaging 2.8%).

Somewhat surprisingly, perhaps, the equation based on Gollop-Jorgenson data suggests the possibility of positive "spillover" effects of government R and D to the industries purchasing inputs from the industries conducting government-financed R and D. In this equation the respective coefficient for the government-financed R and D is larger and stronger than in all the earlier analyses, but it is still not statistically significant.

Among the non–R and D variables, the estimated coefficients are generally similar, but their statistical significance is eliminated, except perhaps for the share of sales in private markets.

6.6 Conclusions

Significant effects of the privately financed industrial R and D on the productivity growth of manufacturing industries were found in earlier research by the author. These effects were two-fold: (1) direct increases in productivity of industries conducting the privately financed R and D, and (2) indirect increases in productivity of industries purchasing capital and intermediate inputs from the industries conducting the privately financed R and D. The estimated indirect effects were considerably larger, per dollar of R and D expenditure, than the direct effects. No comparable effects were found for government-financed industrial R and D.

These findings were tested in this paper for independence of the R and D effects from the possible effects of the previously unmeasured inputs and input characteristics, in general, for human capital, intermediate goods, and composition of physical capital, and for human capital in particular.

The results continue to uphold strongly significant and large estimates of indirect effects of privately financed R and D. There was a weakening of the significance of the estimated direct effects of privately financed R and D, a continued absence of any indication of direct productivity effects of government-financed R and D, and some indication of possible indirect effects of the government-financed industrial R and D. Qualitatively, the results of the tests were consistent with the earlier findings. More detailed research is needed in the future to permit an evaluation of the possible effects of the previously unmeasured inputs, one at a time.

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Comment Steven Globerman

Introduction

Terleckyj's paper is an extension of a rich and interesting study of a slightly earlier vintage (Terleckyj 1974). The earlier study sought to identify separately returns to the R and D conducted within industries and the R and D "purchased" from other industries in the form of embodied technology in capital and intermediate goods. A related concern was to estimate the separate returns to privately financed R and D (both

Steven Globerman is at York University.

"own" and "purchased") and government-financed R and D. The main findings of that study are as follows:

1. For manufacturing industries, direct returns to private R and D were on the order of 30%, in terms of productivity growth; indirect returns were on the order of 80%. The productivity returns, both direct and indirect, to government-financed R and D were estimated at zero.

2. For nonmanufacturing industries, no indication of positive returns to R and D conducted in the industry was obtained. Indirect returns were on the order of 187%.

This conference paper extends earlier findings by attempting to hold constant (either explicitly or implicitly) the effects of increased use of human capital, relative increases in the use of intermediate inputs, and changes in the composition of labor and capital which may have been correlated with increased direct and indirect investment in R and D by the industry.

Before summarizing Terleckyj's empirical results, the basic model underlying the estimation procedure should be briefly reviewed. The underlying model for most estimations is a Cobb-Douglas production function with labor, physical capital, research capital, and a "disembodied" rate of growth of productivity as arguments of the function. By making the usual assumption about equality of factor prices to marginal value products and taking time derivatives of the variables, a reduced-form equation is derived in which the rate of change in an industry's total factor productivity is a linear function of the rate of growth of the intangible stock of R and D capital. Since the growth rate of the R and D capital stock cannot be directly measured, the ratio of gross investment in R and D to output is substituted into the equation. For purposes of estimation, it is assumed that depreciation in R and D capital can be ignored and that the gross investment in R and D capital over the sample period can be measured by the industry's R and D intensity in 1958.

In the estimating equations, the aggregate R and D intensity variable is decomposed by source of financing (private versus public) and by location of conduct (within or without the industry). Additional non-R and D standardizing variables included in all reported estimating equations are percent of sales not made to government, union members as a percent of workers in producing establishments, and annual rate of cyclical change in output. The initial dependent variable is Kendrick's index of total factor productivity compiled for thirty-three manufacturing and nonmanufacturing industries, covering the period 1948–66.

The initial estimation results reported for the sample of twenty manufacturing industries are essentially those of Terleckyj's earlier study, and exclude the effect of changes in input quality and in the use of intermediate inputs. Results for the nonmanufacturing sample are not reproduced, but are reported as above.

In the first extension of his preceding findings, Terleckyj introduces a measure of human capital intensity, based upon the increase in real wages per man-hour worked over the period 1948–66, into earlier estimating equations. He finds that introduction of the human capital measure leaves previous results essentially unaffected, and the coefficient for the human capital variable itself is statistically insignificant.

In a second extension, Gollop-Jorgenson total factor productivity estimates for the twenty manufacturing industries are substituted for Kendrick's estimates in the initial set of estimating equations. The overall statistical results are much poorer than those obtained employing the Kendrick estimates: the adjusted R^2 coefficients decrease substantially, and the "own" privately financed R and D coefficient becomes statistically insignificant. Interestingly, the "purchased" privately financed R and D coefficient remains statistically significant using the Gollop-Jorgenson measure of total factor productivity, and, furthermore, has a greater impact upon productivity than in the earlier equations. Thus, the various specifications of the productivity/R and D relationship provide a range of estimates of the direct and indirect effects of R and D expenditures.

The following discussion will focus primarily upon issues relating to the model specifications, measurement of variables, and potential problems associated with the single-equation estimation procedure. I have no great difficulty in accepting the general nature of Terleckyj's findings. Specifically, to the extent that the performance (or purchase) of R and D is associated with improved quality of conventional factor inputs, one would expect the estimated returns to R and D to be lower when increases in the "quality" of labor and capital are otherwise accounted for. Furthermore, since the numerator of Kendrick's total factor productivity measure is gross output while the denominator excludes intermediate inputs, one would expect estimates of returns to "purchased" R and D to be biased upward if embodied R and D expenditures are positively correlated with the relative use of intermediate inputs. This is bound to be the case for Terleckyj's sample since the imputations of embodied R and D were done by redistributing the R and D expenditures of each industry in proportion to the distribution of sales of that industry to other industries and them summing the amounts attributed to each of the sample industries. The fact that the "purchased" privately financed R and D coefficient increases substantially in the equation employing the Gollop-Jorgenson data suggests the possibility that other, unspecified sources of bias may be present in the estimations.

The observation that the productivity effect of "own" privately financed R and D essentially disappears when "quality" adjustments for labor and capital and the relative use of intermediate inputs are incorporated into the dependent variable (i.e., the Gollop-Jorgenson index) is somewhat difficult to accept on intuitive grounds. If labor and capital resources employed in R and D activities have less risky employment alternatives, one would expect R and D resources to earn their users "excess" returns or be shifted into other activities over time. Part of the explanation for the different results reported in table 6.6 may, indeed, rest in the different methodologies employed to construct the dependent variables. In any case. since the attribution of the productivity effects of R and D will ultimately depend upon how the factor productivity residual is defined, we are somewhat less concerned about explanations of differences in estimated rates of return to R and D across different productivity measures than we are with the identification of returns to R and D employing any given productivity measure. It is the latter concern we will primarily address in our discussion.

Model Specification

The inclusion of input "quality" measures reflects Terleckyj's concern about possible estimation biases arising from the omission from the estimating equation of one (or more) variables whose values differed across sample industries. To the extent that differences in the values of other omitted variables are unsystematically related to the included variables over the sample period, the slope parameters would remain unaffected. However, the brace of standardizing variables employed by Terleckyj excludes certain variables that may be systematically related to the rate of growth in R and D investment.

One such variable is the rate of growth in output in the sample industries over the estimation period. There is ample evidence that industries enjoying above-average productivity growth rates (associated in part, with investments in R and D) also enjoy above-average rates of growth in output. Relative increases in output growth rates could, in turn, affect industry differences in productivity through differential scale and learning economies. Including an output growth rate variable in the estimating equation would raise an identification problem; however, one suspects that its exclusion leads to an upward bias in the estimated R and D parameters.

Another potential source of bias arises from changes in the relative degree of product specialization within industries over time. The derivation of productivity and R and D data along establishment (and product) lines reduces but does not obviate this possibility, particularly given the level of aggregation of the sample industries. One might hypothesize that over the sample period, R and D–intensive industries were becoming relatively more specialized (on an establishment basis), both because a rapidly expanding market for their output facilitated increased specialization and because specialization facilitated entry into high-technology industries.[1] The production and, perhaps more importantly, the learning economies associated with increased product specialization would support the productivity effects of both disembodied and embodied R and D, leading to upward biases in the estimated parameters.

The effect of differential rates of growth in "x-efficiency," in turn related to changes in industrial market structure, might also be embodied in the estimated R and D parameters. An upward bias could be imparted to the R and D coefficients if technological change brings about a decline in average plant size relative to market size. Such a decline could facilitate easier entry into the industry, thereby fostering greater competition and a more efficient allocation of resources, including faster interfirm rates of technological diffusion. Evidence relating changes in concentration ratios to technological change is far from conclusive but, on balance, points to the existence of a negative relationship between the two variables.[2]

The variable used by Terleckyj to standardize for changes in labor quality is the increase in real wages per man-hour worked. The original data for this variable were in the form of period averages of actual hourly earnings for the periods 1948–53 and 1960–66, deflated to 1958 dollars. The annualized percentage change between the two periods was multiplied by the man-hours worked in the industry in the base year, 1958, to obtain the rate of growth in aggregate human capital. The resulting term was then divided by the 1958 value added by the industry to obtain the desired variable.[3] The author acknowledges the possibility of a simultaneous-equation bias arising from the feedback of increased productivity to higher wages, but argues that this bias would not arise if the competitive working of the labor market equalized the earnings within occupations rapidly relative to the length of the period over which the productivity growth is measured. Even if adjustments in the relative supply of labor for different occupations proceeded rapidly (a phenomenon which is certainly at variance with recent evidence on the signifi-

1. The process of entry through specialization in the innovation process is illustrated in the case of the semiconductor industry. See John Tilton, *International Diffusion of Technology: The Case of Semi-Conductors* (Washington: The Brookings Institute), 1971.

2. Examining concentration ratios at the establishment level for different industries over time might provide some feel for the magnitude of this potential bias.

3. Since the numerator of the productivity measure is gross output, it is not evident why the human capital variable, as well as the other standardizing variables, are deflated by value-added in the base year rather than by gross output.

cance of information costs in factor markets), a simultaneous-equation bias might still be obtained if wages (to any significant extent) incorporate expected productivity gains. While it is likely that the Gollop-Jorgenson labor quality measure, based on the shift of workers among different categories, is subject to a smaller simultaneity bias, some bias will still be present if higher wages, in part, are realized in the form of job upgrading.

In light of the acknowledged shortcomings of the labor-quality variable employed, other measures, including the average education level of employees, might have been tested. Median years of schooling of the labor force by industry are available for censal years. While the available censal years 1959 and 1969 do not provide a perfect overlap with the estimation sample period, such exact concordance might not be necessary if relative differences in education levels across industries are reasonably stable over time. The assumption that differences in education levels at a point in time reflect differences in growth rates over the preceding period seems no more heroic than a similar assumption invoked by the author in specifying the R and D variables.

In fact, we reestimated the basic productivity equation across the twenty manufacturing industry sample using Kendrick's index of average education per employee for 1959 (Kendrick 1973) and obtained results quite similar to those obtained by Terleckyj for the growth-in-real-wages variable. The failure to identify a statistically significant positive return to human capital investment for those estimations employing Kendrick's productivity index as the dependent variable is a surprising result. A possible explanation of this result is the existence of multicollinearity between the human capital variables and other included variables. Indeed, the zero-order correlation coefficient between Terleckyj's human capital measure and "own" privately financed R and D equals .58, while the correlation coefficient between the human capital measure and the cyclical change in output is .69. Thus, the influence of human capital investment on productivity growth may be largely assigned to collinear variables in the estimation process.

Measurement of Variables

I will not comment extensively on the problems associated with measurement of variables since Terleckyj considers most of the obvious problems in some detail in his earlier study. Many of the problems are, in any case, intractable given the state of the available data.

The failure of conventional productivity measurements to adequately reflect product quality changes is well-recognized and presumably leads to an underestimation of real rates of productivity change. Insofar as the bias differs among products, the industry comparisons would be affected and, on balance, this probably imparts a downward bias to the estimated

R and D parameters. To the extent that federally financed R and D is primarily directed towards improvements in product quality as opposed to cost reduction, the methodology used in deriving industry productivity estimates could contribute to the finding that government-financed R and D is not significantly related to productivity change. Furthermore, while the period 1948–66 might be long enough compared to the time lag one would expect between privately financed R and D intensity ratios in 1958 and their productivity effects, it might be too short to fully incorporate the effects of federally financed R and D which is presumably aimed at effecting greater changes in underlying production conditions. While Terleckyj's finding of no productivity return to government-financed R and D accords with similar results obtained by Leonard (1971) in a study of interindustry output growth differences, the latter study is subject to the same sorts of criticisms.

The imputations of purchased R and D to the sample industries were done by redistributing the R and D expenditures of each industry in proportion to the distribution of sales of that industry to other industries and then summing the amounts attributed to each of the industries. While imputing embodied R and D as a strict proportion of sales might be no more arbitrary than any other procedure, I would expect that industries performing R and D intensively are more likely to purchase complex and technically advanced equipment than are those industries which perform little R and D. Another imputation procedure might therefore attribute the R and D transferred from a supplier industry to any given purchasing industry as a proportion of the percentage of total sales made to the purchasing industry weighted by the relative "own" R and D intensity of the purchasing industry. In any case, it would be enlightening to evaluate the sensitivity of the statistical results to the imputation procedure used.

A more serious concern is the use of a single year's set of observations to calculate interindustry flows of purchased inputs.[4] Albeit they are dictated by available data, it is certainly possible that observed factor ratios in the given year were not long-run equilibrium values. Indeed, a similar concern might be expressed about most of the independent variables. For example, the "own" R and D intensity variables are measured for a given base year, 1958. In his earlier study, Terleckyj argues that differences in base year R and D intensity levels are likely to reflect differences in preceding R and D growth rates. While this assumption might be quite tenable when comparing high and low R and D–intensive industries, it is somewhat more objectionable for the seven

4. Data for 1958 were employed in developing the "purchased" privately financed R and D intensity variable and the relative growth rate in intermediate inputs variable.

manufacturing industries with "own" privately financed R and D intensity ratios ranging between .2 and .5.

Estimation Procedure

Given the substantial differences in the parameters estimated across the separate samples of manufacturing and nonmanufacturing industries, it is inappropriate to fit common slope parameters for the R and D variables across the full sample of thirty-three industries.

Terleckyj notes that the results for nonmanufacturing industries were erratic, and they can be shown to be highly sensitive, in particular, to the inclusion or exclusion of the air transportation industry. Part of the reason for the sampling instability of the parameters for the nonmanufacturing industry sample might be the substantial collinearity that exists along the basic set of independent variables. Substantial collinearity also exists among specific independent variables for the manufacturing industry sample. Specifically, the zero-order correlation coefficients for pairs of the four R and D intensity variables provided in Terleckyj's table 6.1 (for the sample of twenty manufacturing industries) range between .73 and .95. The simple correlation coefficients between sales other than to government as a percent of total sales and the various R and D intensity variables range between —.79 and —.91. The fact that coefficients for the privately financed R and D variables tend to be unaffected by inclusion or exclusion of the government-financed R and D variables provides a reason for optimism about the reliability of the estimated returns to privately financed R and D. However, this stability might simply reflect the fact that rate-of-return estimates for government-financed R and D are confounded by collinearity with other variables, and particularly with the nongovernment sales variable, so that the private R and D variables are assigned the joint effect of the entire set.

One might also conjecture that the relationship between productivity change and returns to federally funded R and D depends upon the nature and the level of the R and D performed. Specifically, contract R and D performed in the electrical machinery and transportation equipment industries is largely defense-related. Thus, the effects of R and D performance on productivity may be atypical for those two industries. Our own estimation provides some indication that returns to government-financed R and D (both embodied and disembodied) are higher in the above-mentioned industries than in other manufacturing industries. The difference might reflect the existence of increasing returns to federally financed R and D or the possibility that government R and D support to other manufacturing industries is, in effect, a subsidy to offset low rates of productivity growth. These possibilities may be worthy of further investigation.

Concluding Comments

Terleckyj's general findings (for the specifications employing Kendrick's productivity index) are directionally in accord with existing evidence in the literature; however, differences among the various studies in the nature of the samples, the measurement of variables, and the techniques of estimation make specific comparisons rather tenuous. For example, Griliches (1973) obtained an estimated productivity return to R and D of around 40% for a sample of eighty-five two, three, and four-digit manufacturing industries. This estimate includes both direct (i.e., intraindustry) and indirect (i.e., interindustry) productivity effects. Terleckyj's estimates of total R and D returns (employing Kendrick's productivity index) range between 100 and 110% and lie substantially above Griliches's estimated total returns. In another study using a partial productivity measure, Griliches (1975) estimated the rate of return to R and D for 883 large R and D–performing U.S. manufacturing companies. The average gross excess rate of return to R and D was 27% in 1963. It should be noted that this estimate includes the productivity effects of intercompany as well as interindustry technology transfers. Mansfield (1965) found that marginal rates of return to R and D averaged about 40 to 60% for a sample of petroleum firms; for a sample of chemical firms, returns averaged about 30% if technical change was assumed to be capital-embodied but only about 7% if it was disembodied.[5]

Thus, various alternative estimates of the productivity returns to R and D tend to lie somewhat below estimates obtained by Terleckyj, although all of the estimated returns are substantial. Terleckyj's study performs the valuable service of demonstrating that these substantial returns (at least for one productivity measure) cannot be significantly reduced by statistically standardizing for human capital investments in an industry. It also provides us with dramatic evidence that estimated returns to R and D are extremely sensitive to the way in which productivity is measured. However, Terleckyj's study shares a weakness with other studies in failing to hold constant the effects of such factors as changes in average plant size, changes in plant-level specialization, and changes in organizational structure (including intrafirm and interfirm rates of technology diffusion) which may be related to the performance of R and D. An attempt to incorporate the influence of the above-mentioned factors into the basic productivity equation might make a significant contribution to our understanding of the influence of R and D on industrial performance.

5. Mansfield's estimated returns also include the indirect effects of the R and D conducted outside the sample firms.

Finally, Terleckyj should be complimented for the thoughtful inclusion and careful description of the data series included in his estimation work. The inclusion facilitates extension of his interesting work by other researchers.

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