The contribution of R&D to productivity growth

Results of a BLS study suggest that the direct contribution of research and development to postwar productivity growth was between 0.1 and 0.2 percent annually in the nonfarm business sector; R&D had no substantial effect on the post-1973 productivity slowdown

LEO SVEIKAUSKAS

Many observers believe that research and development (R&D) conducted in U.S. industry is an important ingredient in the Nation's productivity improvement.[1] The Bureau of Labor Statistics has recently conducted work aimed at establishing the contribution of R&D to productivity growth.[2] The study proceeded along much the same lines as prior BLS analysis of the contribution of the physical capital stock to productivity.[3] This work calculated real annual investment in research and development and estimated the R&D stock to determine the annual and long-term productivity effects of research spending in the private nonfarm business sector. This article summarizes the main conclusions which have emerged from that analysis.

Between 1948 and 1982, U.S. multifactor productivity growth—the increase in output beyond the contribution of labor and capital inputs—was 1.2 percent per year. However, the long-term productivity trend for the postwar period reflects very different developments during two distinct subperiods. Multifactor productivity increased at an annual rate of 1.7 percent from 1948 to 1973, but then decreased by 0.2 percent per year through 1982. The results reported below indicate that the R&D stock contributed 0.1–0.2 percent annually to 1948–82 productivity growth, but had no substantial effect on the 1973–82 productivity slowdown.

Research and development provides both *direct* productivity benefits to industries conducting research, such as computer or aircraft manufacturers, and *indirect* benefits to industries further along the chain of production, as occurs when banks take advantage of new computer technology or commercial airlines realize gains from the purchase of better aircraft. This study deals only with the direct productivity benefits accruing to industries actually conducting the research. The reader should realize that, on balance, the indirect benefits gained as new technology spreads to other parts of the economy are likely to be greater than the direct contribution of research. Future Bureau work will attempt to determine the magnitude of these indirect effects.

Main elements of the analysis

At least eight distinct issues have to be considered in developing an estimate of the R&D stock and determining its influence on productivity growth. The following discussion summarizes the decisions that the Bureau reached on each of these matters. In several instances, economic understanding is at present not sufficient to support a definite judgment concerning the proper treatment of an issue. In these cases, an assumption which appears reasonable in light of prior

Leo Sveikauskas is an economist in the Division of Productivity Research, Bureau of Labor Statistics.

analysis was selected for use in the "preferred" model. However, sensitivity analyses also examined the effect of other plausible assumptions on conclusions about the relationship between R&D and productivity growth.

Defining the R&D stock. The first and main issue is determination of the components of research that should be included in the R&D stock, which establishes the central framework for the study. BLS measures of productivity in the major economic sectors rely upon data published in the national income accounts. Therefore, the components of research that should properly be included in the R&D stock are those that *directly* affect productivity growth as measured within the context of the national income accounts. Most analyses of R&D indicate that only privately financed research directly affects typical measures of productivity.[4] However, there is also some evidence that government-financed research conducted in industry affects measured productivity, although less strongly.[5]

In view of this information, the preferred measure of the R&D stock selected for this study includes only privately financed research conducted in industry and the relatively small, privately financed projects conducted in colleges and universities or nonprofit institutions, which are assumed to be similar in nature. However, the sensitivity analyses discussed below also consider an alternative measure that includes government-financed research conducted in industry, weighted at 20 cents on the dollar.

The Bureau's definition of the R&D stock includes both product and process research, and both basic and applied research, although separate accounts are kept for the latter two categories to permit differential treatment of lag and depreciation issues. The R&D stock is here limited to research conducted by U.S. industry. Detailed specification of the influence of foreign research on the U.S. economy remains an important topic for future empirical investigation.

Locating appropriate data. Once the relevant definition of R&D was decided, it was necessary to obtain data on annual expenditures for the categories of research included. Annual publications of the National Science Foundation provide the necessary information from 1953 onwards.[6] Nestor Terleckyj has prepared similar consistent annual data on private R&D expenditures for the years 1921–52.[7] The alternative measure of the research stock, which includes government-financed research conducted in industry, relies on data developed by David Blank and George Stigler.[8]

Converting to constant dollars. The third step in the analysis requires selection of an appropriate R&D deflator to convert annual research spending into constant-dollar terms. The National Science Foundation uses the GNP deflator for this purpose, although it is widely recognized that this series provides only a very rough approximation. Zvi Griliches has suggested an alternative deflator that weights the output price deflator for nonfinancial corporations at 0.51 and the unit compensation index for the same sector at 0.49.[9] The BLS study adopts the Griliches deflator, suitably modified to adjust research expenditures occurring before 1958, the first year for which nonfinancial corporations data are available.

Determining the appropriate lag time. Once real annual research expenditures are estimated, the lag between the time research is conducted and the time it affects productivity must be considered. On the basis of a review of the relevant literature, a 2-year lag was selected for applied research and a 5-year lag was chosen for basic research. One-year and 3-year lags for applied research were examined in the sensitivity analyses.

Treating depreciation. A fifth crucial issue is whether the R&D stock depreciates over time, in the sense of contributing less to output. If so, what is the time path and pattern of this depreciation? The literature contains a broad range of conclusions on this topic, from some which suggest that R&D investments do not depreciate at all to others which indicate rapid depreciation of research expenditures.[10]

For this study, a depreciation pattern known as 0.1 geometric decay, which implies that 10 percent of the research stock depreciates each year, was selected as the preferred choice for applied research. Basic research was assumed not to depreciate. The sensitivity analyses also examine the effects of alternatively assuming zero or 0.2 geometric decay for applied research. As the discussion of the findings shows, the choice of a rate of depreciation has a substantial impact on conclusions concerning the effect of R&D on productivity growth. Unfortunately, not much is definitively known about depreciation of the R&D stock.

Calculating the R&D stock. The research stock was calculated using standard perpetual inventory methods which determine each year's net change in the stock by allowing for new investment and for depreciation.

Deciding on a rate of return. The seventh matter to be considered is the appropriate rate of return to apply to the research stock to determine its contribution to productivity growth. On the basis of a broad range of empirical studies, a 30-percent real rate of return was selected for use in the preferred measure.[11] On the basis of a review of the relevant literature, it was assumed that there has been no decline in the rate of return over time.[12] However, the sensitivity analyses also examined the impact on productivity growth if there has been a substantial decline in the rate of return to R&D over time.

Determining the impact of R&D. In the final step, information on the R&D stock and its assumed rate of return was combined to estimate the impact of research on productivity. This was determined by calculating the research share of output in the private nonfarm business sector and multiplying this share by the growth rate of the research stock. Such a procedure is standard in analyzing the contribution of inputs to economic growth.

In these calculations, the research stock is first multiplied by the assumed real rate of return (.30) to determine annual-real research income. Research income is then divided by real output in the private nonfarm business sector to obtain the research share in the sector. Finally, the research share is multiplied by the annual percentage increase in the R&D stock to determine the contribution to productivity growth.[13]

Empirical results

Table 1 presents the preferred estimates of the impact of R&D on productivity growth. All results are for the private nonfarm business sector for the 1948–82 period.

Column 1 shows the R&D stock of the sector in 1972 dollars. Over the 1948–82 period, the research stock grew at an average annual rate of 6.8 percent. From 1948 to 1973, growth was 7.8 percent a year, but the pace slowed considerably—to 4.3 percent—during the 1973–82 period.

Estimates of year-to-year change in column 2 also indicate that the growth of the R&D stock slowed substantially in the 1970's. By that time, however, the research share of sector income (column 5) was considerably greater than it had been in the immediate postwar years because of the consistent substantial growth in the R&D stock. The weight of research in the economy was therefore greater in recent years, and each percentage-point increase in the R&D stock made more of a contribution to output growth. Consequently, the overall contribution of R&D held up better in the 1970's than the slowing growth rate of the research stock itself would suggest.

Estimates for the subperiods 1948–73 and 1973–82 indicate that R&D had no substantial impact on the post-1973 productivity slowdown. From 1948 to 1982, R&D contributed 0.14 percent a year to multifactor productivity growth. Subperiod rates were essentially the same: 0.14 percent from 1948 to 1973, and 0.13 percent from 1973 to 1982.[14]

The annual productivity contributions shown in column 6 provide a more detailed view of the impact of R&D on productivity. The annual productivity contribution ranged between 0.16 and 0.18 in the 1960's, but declined to about 0.11 to 0.12 in the late 1970's. However, by the early 1980's, the productivity contribution of R&D had essentially returned to the magnitudes reached in the 1960's.

Table 1. Central variables and results from analysis of the effects of research and development on productivity growth, private nonfarm business sector, 1948–82

[In billions of 1972 dollars, unless otherwise indicated]

Year	R&D stock		Output of private nonfarm business[1]	Real R&D income[2]	R&D share of total output[3] (in percent)	R&D contribution to productivity growth[4] (in percent)
	Level	Annual growth rate (in percent)				
	(1)	(2)	(3)	(4)	(5)	(6)
1948...	$13.5	—	$364.5	$4.0	—	—
1949...	14.6	8.8	357.5	4.4	1.2	0.10
1950...	15.8	8.0	392.2	4.7	1.2	.09
1951...	16.5	4.6	418.0	5.0	1.2	.05
1952...	17.5	6.1	432.2	5.3	1.2	.07
1953...	18.5	5.7	451.0	5.6	1.2	.07
1954...	20.1	8.3	442.0	6.0	1.3	.10
1955...	22.4	11.4	479.1	6.7	1.4	.15
1956...	24.6	9.9	492.7	7.4	1.4	.14
1957...	26.7	8.9	498.6	8.0	1.6	.13
1958...	29.9	11.8	488.9	9.0	1.7	.19
1959...	32.8	9.6	528.2	9.8	1.8	.17
1960...	35.6	8.4	535.5	10.7	1.9	.16
1961...	38.6	8.5	545.2	11.6	2.1	.17
1962...	41.9	8.5	577.3	12.6	2.1	.17
1963...	45.1	7.7	602.8	13.5	2.2	.16
1964...	48.4	7.3	641.2	14.5	2.3	.16
1965...	51.9	7.1	685.8	15.6	2.3	.16
1966...	55.5	6.9	726.5	16.6	2.3	.15
1967...	59.5	7.3	741.9	17.9	2.3	.17
1968...	63.9	7.4	782.2	19.2	2.4	.17
1969...	68.7	7.4	805.0	20.6	2.5	.18
1970...	73.6	7.1	796.6	22.1	2.7	.18
1971...	78.7	7.0	819.9	23.6	2.8	.19
1972...	83.3	5.8	877.7	25.0	2.9	.16
1973...	87.4	4.9	938.1	26.2	2.8	.13
1974...	91.5	4.7	917.9	27.5	2.9	.13
1975...	96.2	5.0	896.3	28.8	3.1	.15
1976...	100.6	4.6	957.9	30.2	3.2	.14
1977...	104.1	3.5	1023.3	31.2	3.1	.11
1978...	108.0	3.8	1081.7	32.4	3.0	.11
1979...	112.1	3.8	1105.0	33.6	3.0	.11
1980...	116.7	4.1	1088.7	35.0	3.1	.12
1981...	121.8	4.4	1112.3	36.5	3.3	.14
1982...	127.7	4.8	1083.4	38.3	3.4	.16

[1] Constant-dollar output of the sector. All calculations were conducted prior to the January 1985 GNP revisions.

[2] Column (1) × 0.30, under the assumption of a 30-percent rate of return on the research stock.

[3] Column (4) divided by column (3).

[4] To illustrate the methodology adopted to generate these estimates, the 1948–49 growth in the research stock, .088 (or 8.8 percent), is multiplied by the research share, .012 (or 1.2 percent), to determine the productivity contribution, which is .0010, or 0.10 percentage points. Text footnote 13 describes the actual method used, which tends to result in slightly lower contributions.

Other major sectors. The analysis so far has concentrated on the impact of the research stock in the nonfarm business sector. It is difficult to obtain a reliable time series for direct private research investment in the farm sector, and that sector is therefore not examined here. The heavy expenditures by Federal and State governments on agriculture can probably best be viewed as indirect research provided to the farm sector by other industries, and therefore are also not considered in this report.

In addition, it is difficult to establish a reliable basis on which to divide nonfarm business research between its manufacturing and nonmanufacturing components. Tentative estimates suggest that research and development may have contributed as much as 0.41 percent per year to 1948–82 productivity growth in manufacturing, but only 0.01 percent to direct productivity growth in the nonmanufacturing sector. These very different effects of the direct impact of research arise because an extremely large proportion of direct research spending takes place in manufacturing.

Sensitivity analyses

The preferred results summarized above are based on a 2-year lag between applied research and its effect on productivity, 0.1 geometric depreciation, use of the Griliches deflator to convert research expenditures into real terms, inclusion of only privately financed research, and a constant rate of return to the research stock over time. But, as indicated earlier, these assumptions are subject to some uncertainty because much remains to be known about the economics of R&D. Therefore, a sensitivity analysis was conducted to determine how other plausible assumptions affect the central conclusions concerning the influence of R&D. The first line of table 2 lists the productivity impacts with the preferred assumptions. These figures provide the base-case framework, which is used as the standard of reference for examining the effects of using alternative assumptions in the model.

Changes in the lag before applied research influences production have little effect on long-term productivity growth. If a 1-year lag is adopted, the R&D impact is slightly greater (line 2), essentially because the research stock is then somewhat larger. However, there is no substantial change in the effect of R&D on productivity. If a 3-year lag is assumed instead (line 3), there is no change at all in the implied influence of R&D on productivity growth.

In contrast, changes in the assumed rate of depreciation have a major impact on the implied influence of R&D. If there is zero depreciation, the research stock increases more rapidly and is larger at every given time, both of which suggest that R&D contributes more to productivity. With zero depreciation (line 4), research contributes 0.33 percent to 1948–82 productivity growth; the 1948–73 contribution of 0.31 percent increases to 0.40 percent in 1973–82 as the R&D stock continues to grow.

Table 2. The effect of alternative assumptions on the implied influence of the research and development stock on productivity growth, 1948–82 and two subperiods

Alternative assumption	R&D contribution to productivity growth[1] (in percent)		
	1948–82	1948–73	1973–82
1) Preferred estimate	0.14	0.14	0.13
2) 1-year lag for applied research	.15	.15	.14
3) 3-year lag for applied research	.14	.14	.13
4) Zero depreciation of applied research	.33	.31	.40
5) 0.2 geometric depreciation of applied research	.09	.10	.08
6) GNP deflator used to deflate research expenditures	.14	.14	.14
7) Two-tenths of Federally funded research conducted in industry counted in the research stock	.16	.17	.13
8) The real rate of return to research declines over time[2]	.13	.14	.10

[1] See footnote 4, table 1.

[2] Assumes a linear decline from 30 percent in 1967 to 20 percent in 1982.

Conversely, if 0.2 geometric decay is assumed for applied research (line 5), the R&D stock grows more slowly and is smaller, so that R&D contributes only 0.09 percent to 1948–82 productivity growth, 0.10 percent in 1948–73 and 0.08 percent in 1973–82. These amounts are moderately less than in the preferred case. Because the depreciation of R&D has important implications for the role of the research stock in productivity growth, further study of this issue would be highly useful.

If the GNP deflator is used instead of the Griliches deflator (line 6), the original results are not greatly changed. However, if two-tenths of the Federal expenditures for research conducted in industry are included (line 7), the 1948–82 productivity contribution is 0.16 percent, reflecting the greater research stock. In addition, R&D plays a greater role in the productivity slowdown, with its contribution declining from 0.17 percent in 1948–73 to 0.13 percent in 1973–82. This reflects the fact that the growth of Federally financed research conducted in industry slowed more during the 1970's than did privately financed research spending. Nevertheless, even if the Federal funds are included, the implied R&D effects on productivity growth (and the productivity slowdown) are not very great.

Finally, line 8 presents the case in which the rate of return declines linearly from 30 percent in 1967 to 20 percent in 1982. The productivity contribution of R&D is slightly lower for 1948–82 as well as for 1973–82. However, once again the contribution to the productivity slowdown is less than one-tenth of a percentage point.

In summary, the preferred estimates of the impact of R&D on productivity growth are fairly robust with respect to changes in the central assumptions used in constructing them. The exception is the rate of depreciation: under the zero depreciation assumption, the effect of R&D on productivity is substantially greater.[15]

THE CONCLUSIONS drawn here must be qualified because they deal only with the *direct* return to research and development. The indirect effects of research are likely to be greater, but because they take longer to appear, the slowdown in research spending in the late 1960's and the 1970's is probably not yet fully reflected in productivity measures. The Bureau of Labor Statistics plans further study of the indirect effects of R&D.

More generally, although R&D has received much attention, it represents only a portion of the many social and individual activities relevant to technical progress. Managerial and organizational quality, the integration of the industrial relations system with effective technological change, and technological achievements by individual inventors or entrepreneurs all are important facets of technical change. These aspects of innovation are also likely to have had a substantial impact on productivity growth but are, regrettably, extremely difficult to quantify on a comprehensive national basis. □

——FOOTNOTES——

[1] A National Academy of Sciences report which suggested improvements in the Nation's productivity statistics paid substantial attention to the role of research and development in productivity growth. See *Measurement and Interpretation of Productivity* (Washington, National Academy of Sciences, 1979). John W. Kendrick and Elliot S. Grossman find research and development to be the most important factor affecting interindustry differences in productivity growth. See *Productivity in the United States: Trends and Cycles* (Baltimore, MD, The Johns Hopkins Press, 1980). See also Zvi Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics*, Spring 1979, pp. 92–116.

[2] Recent BLS work on this topic is summarized in *Research and Development and Productivity Growth* (Bureau of Labor Statistics, forthcoming).

[3] The Bureau's work on the influence of physical capital on productivity is summarized in Jerome A. Mark and William H. Waldorf, "Multifactor productivity: a new BLS measure," *Monthly Labor Review*, December 1983, pp. 3–15. A detailed discussion of the effect of capital on productivity is contained in *Trends in Multifactor Productivity, 1948–1981*, Bulletin 2178 (Bureau of Labor Statistics, September 1983).

[4] William N. Leonard, "Research and Development in Industrial Growth," *Journal of Political Economy*, March 1971, pp. 232–56; and Nestor E. Terleckyj, "Research and Development and U.S. Industrial Productivity in the 1970's," in Devendra Sahel, ed., *The Transfer and Utilization of Technical Knowledge* (Lexington, MA, Lexington Books, 1982), pp. 63–99.

[5] David M. Levy, and Nestor E. Terleckyj, "Effects of Government Research and Development on Private R and D Investment and Productivity: A Macroeconomic Analysis," *Bell Journal of Economics*, August 1983, pp. 551–61; Zvi Griliches, "Returns to Research and Development Expenditures in the Private Sector," in John W. Kendrick and Beatrice N. Vaccara, eds., *New Developments in Productivity Measurement and Analysis* (Cambridge, MA, National Bureau of Economic Research, 1980), pp. 419–54; and Zvi Griliches, "Productivity, R and D and Basic Research at the Firm Level in the 1970's," Discussion Paper 1124 (Cambridge, MA, Harvard Institute of Economic Research, 1985).

[6] National Science Foundation, *Research and Development in Industry*, various issues; and National Science Foundation, *National Patterns of Science and Technology Resources*, various issues.

[7] Nestor E. Terleckyj, "R and D as a Source of Growth of Productivity and Income," Working Paper (Washington, National Planning Association, May 18, 1982).

[8] David B. Blank and George J. Stigler, *The Demand and Supply of Scientific Personnel* (New York, National Bureau of Economic Research, 1967).

[9] Zvi Griliches, "Comment (on Mansfield)," in Zvi Griliches, ed., *R and D, Patents and Productivity* (Chicago, University of Chicago Press, 1984), pp. 148–49.

[10] Ariel Pakes and Mark Schankerman, "The Rate of Obsolescence of Patents, Research Gestation Lags and the Private Rate of Return to Research Resources," in Griliches, ed., *R and D, Patents and Productivity*, pp. 73–88; Terleckyj, "Research and Development and U.S. Industrial Productivity in the 1970's"; and Zvi Griliches and Frank Lichtenberg, "Research and Development and Productivity at the Industry Level: Is There Still a Relationship?" in Griliches, ed., *R and D, Patents and Productivity*, pp. 465–96.

[11] There are two types of studies which provide evidence on the rate of return to research and development: regression studies of industry or firm productivity growth and studies of returns to specific representative R&D projects. Regression evidence is subject to many well-known qualifications, such as omission of relevant variables. Therefore, it is important to emphasize that the studies of the returns to specific research projects suggest conclusions broadly comparable with the evidence from the regression analysis of productivity. The consistency between these two different strands of evidence greatly increases the confidence which can be placed in the implied relationship between R&D and productivity growth.

Important regression studies include Zvi Griliches, "Research Expenditures and Growth Accounting," in B.R. Williams, ed., *Science and Technology in Economic Growth* (New York, Macmillian Co., 1973), pp. 59–95; Nestor E. Terleckyj, *Effect of Research and Development on the Productivity Growth of Industries: An Exploratory Study* (Washington, National Planning Association, 1976); Zvi Griliches, "Returns to Research and Development Expenditures in the Private Sector"; Leo A. Sveikauskas, "Technology Inputs and Multifactor Productivity Growth," *Review of Economics and Statistics*, May 1981, pp. 275–82; Frederic M. Scherer, "Interindustry Technology Flows and Productivity Growth," *Review of Economics and Statistics*, November 1982, pp. 627–34; and Zvi Griliches and Frank Lichtenberg, "Interindustry Technology Flows and Productivity Growth: A Reexamination," *Review of Economics and Statistics*, May 1984, pp. 324–29.

The most important studies of the returns to representative projects are Edwin Mansfield, John Rapoport and others, "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics*, May 1977, pp. 221–40; and J. G. Tewksbury and others, "Measuring the Societal Impact of Innovations," *Science*, Aug. 8, 1980, pp. 658–62, including the further references cited there.

Many regression studies of the impact of research and development on productivity growth measure the increase in the research stock as observed research spending. If research investments depreciate, these regression studies may substantially underestimate the true return to research. In this context, the Mansfield case-study evidence was especially helpful in ensuring that the return to research selected for the present study is realistic.

[12] Studies which find no substantial change in the rate of return to R&D over time includes Zvi Griliches and Frank Lichtenberg, "Interindustry Technology Flows"; Kim Clark and Zvi Griliches, "Productivity Growth and R and D at the Business Level: Results from the PIMS Data Base," in Griliches, ed., *R and D, Patents and Productivity*, pp. 393–416; and Griliches, "Productivity, R and D and Basic Research at the Firm Level in the 1970's."

A somewhat earlier study presents evidence indicating the rate of return to research may have declined and considers some of the reasons why such a declining return is plausible. See Edwin Mansfield, "How Research Pays Off in Productivity," *EPRI Journal*, October 1979, pp. 25–28.

[13] The share of research and development in any year can be calculated by multiplying the research stock times the assumed real rate of return (.30) to obtain implied real research income, and dividing the result by real output.

The research share indicated for each year in table 1 is obtained by calculating S_{t-1}, the research share for the first year of any binary comparison, and S_t, the corresponding research share in the second year. The share used, S_t^*, is then calculated as $S_{t-1} + S_t)/2.0$, or the average share for the two years in question. The contribution to productivity growth is then obtained from $S_t^* \; (logR_t - logR_{t-1})$, where R_t and R_{t-1} are the values of the research stock in the two years under consideration. The logarithmic form here indicates that growth rates are measured in continuous rather than discrete terms. Appendix A of the forthcoming BLS Bulletin *Research and Development and Productivity Growth* provides more complete information on the procedures used here.

The bulletin also includes a more detailed discussion of the various ways in which economists have examined the impact of R&D and the many complex issues which must be addressed in developing quantitative measures. Current understanding in this area leaves several important matters unresolved. In particular, the possibility of quality improvement in the R&D sector and the interactions between basic and applied research deserve further attention.

[14] The average annual productivity contribution for each of the periods considered was calculated as the geometric mean of the relevant annual contributions listed in column 6 of table 1.

[15] However, with the zero depreciation assumption, the contribution of R&D increases about one-tenth of a percentage point from 1948–73 to 1973–82; R&D not only does not contribute to the productivity slowdown, but is a positive force which tends to offset some of the slowdown occurring for other reasons.