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4 Productivity, R&D, and Basic Research at the Firm Level in the 1970s

This paper reports new results on the relationship of research and development (R&D) expenditures, especially expenditures on basic research, to productivity growth in U.S. manufacturing firms during the 1970s. It is based on a unique data set, the National Science Foundation (NSF) R&D-Census match, containing information on R&D expenditures, sales, employment, and other detail for approximately 1000 largest manufacturing firms from 1957 through 1977. It updates my earlier work (1980) on the precursor of this data set, replicates some of Edwin Mansfield's (1980) work on the contribution of basic research to productivity growth using a larger, more recent, and more representative sample of firms, and complements similar work by myself and J. Mairesse (1983, 1984) based on a publicly accessible but more limited data set.

Two topics are explored in some detail: 1) Is there any evidence of a decline in the returns to industrial R&D expenditures, a decline in their "fecundity" in the 1970s as compared to earlier time periods? 2) Is there evidence that basic research is a relatively more important component of R&D and that there may have been an underinvestment in this component?

A few background facts are worth stressing at this point. In the United States, total R&D expenditures in industry peaked (in real terms) around 1968, dropped slightly in the early 1970s and recovered somewhat in the late 1970s. Relative to total sales, R&D expenditures in industry declined from 4.2 percent in 1968 to a trough of 2.6 percent in 1979 and then recovered to 3.7 percent by 1982. This pattern masks a strong divergence between the trends in federally and privately supported industrial R&D. Federally supported R&D fell

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from 2.1 percent of manufacturing sales in 1967 to 0.7 percent in 1979 and has only recently begun to recover, while company-financed R&D stayed essentially constant (relative to industry sales) with almost all of the fluctuation coming from the decline in federal support (NSF, 1983; 1984). During the same period, the economy experienced one of the sharpest and most prolonged recessions of the postwar period and a large and pervasive productivity slowdown. Hardest hit were the primary metals, motor vehicles, and other heavy, energy-related industries. On the whole, these were the less R&D intensive industries, resulting in a largely accidental correlation between R&D intensiveness and the productivity slowdown. (See my 1980b paper and my article with F. Lichtenberg, 1984, for more discussion of these issues.)

The remainder of the paper is organized as follows. First, I describe the data set with its advantages and limitations and present some overall comparative statistics. Second, I outline briefly the framework that underlies the computations to be performed. The results are presented and discussed, and the paper closes with some conclusions, caveats, and suggestions for further research.

4.1 Previous Work and the Current Data Set

The current project is an extension of work originally begun in the mid-1960s. That work was based on the matching of R&D data collected on behalf of the NSF by the Bureau of the Census during 1957–65 with additional company data from the 1958 and 1963 Census of Manufactures and Enterprise Statistics. The universe consisted of large (1000 or more employees) U.S. manufacturing companies performing R&D. The final sample of 883 of such companies accounted for over 90 percent of total sales and R&D expenditures of all firms in this universe.

The main finding of that work (see my 1980a paper) was a rather consistent and positive relationship between various measures of company productivity and its investments in research and development. The Cobb-Douglas-type production functions, estimated on both levels (1963) and rates of growth (1957–65) yielded an elasticity of output with respect to R&D investments of about .07 and an implied average gross excess rate of return of 27 percent (as of 1963), a significantly lower rate of return to federally financed R&D expenditures, and no clear evidence of significant scale effects either in R&D investment policies or the returns from it.

In trying to extend the earlier study to the more recent time period, it became clear that the earlier work could not be simply updated because much of the earlier data was lost and a new data set had to be created instead. The basic objective was to create a matched body of data on most of the large R&D performing corporations in the United States, making it possible to analyze both the determinants and consequences of R&D spending *over time*. For this purpose a time-series record has been created for each company consisting of the major variables in the annual R&D survey for each of the years 1957–77, supplementary R&D information for selected years (1962, 1967, 1972, and 1975), data from the Enterprise Statistics (i.e., company level questionnaires) for 1967, 1972, and 1977, and a few additional items from the Census of Manufactures establishment record summaries for 1967 and 1972. The data set began with all the "certainty" companies in the NSF R&D survey as they existed in 1972. There were approximately 1100 such companies, but a "complete" record is available only for a much smaller number.[1]

Table 4.1 lists the sample size, means, and standard deviation for the major variables as of 1972 and their growth rates from 1966 to 1977. It is intended to describe three aspects of these data: 1) the general characteristics (means and standard deviations) of the sample as of 1972; 2) average rates of growth of the major variables of interest during the 1967–77 period; and 3) how these measures change when the sample is changed to select observations according to the availability of the requisite information.

Turning to the last topic first, note that we tend to lose smaller and more R&D intensive firms as the sample gets more restrictive. The first column of Table 4.1 corresponds to the most liberal criterion: a firm had to exist in 1972 and report positive R&D. Column 2 requires both the ability to compute a growth rate for the 1967–77 period (i.e., at least five good time-series observations) and a successful match to the 1972 Census of Enterprise data (NCK–1). In column 3, I add the requirement of a successful match to the 1977 Census data, while in column 4 the subsample is based on a match with the 1967 and 1972 Census data instead. The major differences occur in the transition from column 1 to column 2 where trying to match to the Census we lose a relatively large number of smaller firms for which there are still data in the R&D survey files. The firms that can be also found in the 1977 Census are slightly larger and have had a somewhat higher rate of growth in employment, R&D, and productivity. The firms that also existed in 1967 are even larger but have on average grown somewhat more slowly than those that existed in the 1972–77 period. If we look at two of the major variables of interest, partial productivity growth and the ratio of basic to total R&D, there is almost no difference in their means across the relevant columns (2, 3, and 4), and hence it is unlikely that subsequent conclusions will be subject to a serious sample selection bias. I will, therefore, ignore this topic here.

Looking at the levels of the variables in 1972, we see that the average firm in the sample is quite large (5000+ employees), employs close to one hundred R&D scientists and engineers, and is making only a relatively modest invest-

1. The universe of this data match consists of all "certainty" cases in the 1972 R&D survey; i.e., the basic definition is the population of companies as they existed in 1972 (as against 1962 in the earlier study) and the requirement of "certainty" assures that the Census Bureau tried to collect consistent data for these firms for more than one year. The "certainty" cases correspond closely to the earlier restriction to companies with 1000 or more employees, though it is a bit more inclusive. See my paper with Bronwyn Hall (1982) and Hall (1984) for more detail on sample definition and variable construction.

Table 4.1 **Major Variables in 1972 and 1966–77 Growth Rates by Subsample: Means and Standard Deviations**[a]

	Data Set, Selection Criteria, and Sample Size			
Variable	1972 R&D Survey Universe (N = 1105) (1)	1966–77 Growth Rate Computable and Matched to 1972 Census (N = 652) (2)	(2) and Matched to 1977 Census (N = 491) (3)	(2) and Matched to 1967 Census (N = 386) (4)
A. Levels in 1972				
Sales in Million Dollars	146	205	223	236
	(1.61)	(1.43)	(1.40)	(1.44)
Total Employment	4038	5570	6212	6698
	(1.48)	(1.27)	(1.30)	(1.31)
R&D Scientists and Engineers	89	74	82	106
	(1.66)	(1.70)	(1.71)	(1.72)
R&D in Million Dollars	2.3	3.0	3.4	4.3
	(1.74)	(1.78)	(1.77)	(1.83)
R&D to Sales Ratio (*RS*)	.051	.033	.032	.035
	(.131)	(.064)	(.051)	(.048)
Company R&D/Sales Ratio (*CRS*)	.028	.022	.023	.025
	(.069)	(.026)	(.026)	(.026)
Basic to Total R&D Ratio (*BR*)	.025	.026	.026	.027
	(.074)	(.071)	(.075)	(.073)
Value-Added, Million Dollars		100	113	121
		(1.32)	(1.31)	(1.34)
Gross Fixed Assets Million Dollars		115	124	147
		(1.67)	(1.59)	(1.65)
B. Growth Rates 1966–77				
Employment Growth		.012	.015	.006
		(.046)	(.041)	(.040)
Partial Productivity Growth (*BPT*)		.025	.026	.025
		(.036)	(.034)	(.035)
Total R&D Growth, Deflated (*BTRD*)		−.001	.003	−.007
		(.079)	(.074)	(.070)
Scientists and Engineers Growth		.008	.012	.004
		(.087)	(.084)	(.078)
Company R&D Growth, Deflated (*BCRD*)		.004	.008	−.000
		(.081)	(.076)	(.071)

Notes: Col. 1: "Certainty" firms in the NSF R&D Survey with positive R&D in 1972; Col. 2: Growth rates for 1966–77 computable (at least 5 years of good data on sales, employment, and R&D) and a successful match to the 1972 Enterprise Census (NCK–1); Col. 3: (2) and a successful match to the 1977 Census (NCK–1); Col. 4: (2) and a successful match to the 1967 Census and growth rates computable for 1957–65; Partial productivity growth = deflated sales growth − (share of labor compensation in total sales) × growth in employment; Sales deflated by NIPA based output price indexes at the 2–3 digit SIC level. R&D deflator based on the methodology suggested by Jaffe (NSF 1972), from my 1984 comment.

[a]Geometric means and standard deviations (shown in parentheses) of the logarithms (approximate coefficient of variation) except for growth rates or ratios.

ment of its own money (about 2.5 percent of sales) in R&D, with very little of that, less than 3 percent, being devoted to basic R&D. This picture is somewhat misleading, however. The actual distribution of firms is quite skewed, with a small number of larger firms spending much larger amounts on both total and basic R&D. Looking at growth rates one can observe that on average these firms grew only moderately during this period: about 1 percent per year in total employment, about 2.5 percent per year in partial productivity, and almost zero growth in deflated R&D expenditures (though a slightly positive rate of growth in the number of R&D scientists and engineers). Here again, while on average there is little movement, there is a great deal of variability at the individual firm level. The standard deviations of the rates of growth of partial productivity and total R&D are 3.5 and 8 percent per annum, respectively, with many firms growing much faster (and also much slower) than the average.

Looking at some of the R&D ratios over time, not reported in Table 4.1, one cannot see any significant decline in the rate of private investment in R&D. While the total R&D to sales ratio falls from .042 in 1962 to .035 in 1972 and again from .032 in 1972 to .029 in 1977 for firms in subsamples 4 and 3, respectively, the company-financed R&D to sales ratios (*CRS*) are essentially unchanged (.025 in 1962 and 1972 in subsample 4 and .023 in 1972 and 1977 in subsample 3). On the other hand, while the basic research ratio (*BR*) fell only modestly from .033 to .031 between 1962 and 1972, and from .027 to .023 between 1972 and 1977, coupled with the decline in the overall total R&D to sales ratio, this implies about a 40 percent reduction in the relative intensity of industrial investment in basic research, relative to industry sales. Almost all of this decline came from the overall decline in federally financed R&D which declined from about 55 percent of total R&D in industry in 1965 to about 35 percent in 1982. The federal government financed about 32 percent of all basic research in industry in 1967 but only 19 percent in 1982 (see NSF, 1983 and 1984). The reduction was so steep that basic research in industry declined not only relatively (to sales) but also absolutely, from a peak of $813 million in 1966 (in 1977 dollars) to a trough of $581 million in 1975 and did not surpass the 1960s levels until the early 1980s. How one interprets the consequences of such a decline depends on one's view of the relative productivity of governmentally financed R&D expenditures in industry, a topic I will be exploring below.

4.2 The Analytical Framework and Econometric Results

The work reported here focuses primarily on the analysis of productivity growth for these companies, using a rather simple Cobb-Douglas production function approach:

$$Q_t = Ae^{\lambda t}K_t^{\alpha}C_t^{\beta}L_t^{1-\beta}, \tag{1}$$

where Q is output (sales, or value-added), C and L are measures of capital and labor input, respectively, $K = \sum_i w_i R_{t-i}$ is a measure of the accumulated and still productive research capital ("knowledge"), R_t measures the real (deflated) gross investment in research in period t, and the w_i's connect the levels of past research to the current state of knowledge. In addition, λ measures the rate of disembodied "external" technical change (where t is time in years), A is a constant, and constant returns to scale have been assumed with respect to the conventional inputs (C and L).

A number of serious difficulties arise when one turns to the operational construction of the various variables (see my 1979 article for more detailed discussion). Perhaps the two most important problems are the measurement of output (Q) in a research-intensive industry (where quality changes may be rampant), and the construction of the unobservable research capital measure (K). Turning to the second problem first, note that $K_t = \sum w_i R_{t-i}$ can be thought of as a measure of the distributed lag effect of past research investments on productivity. There are at least three forces at work here: the lag between investment in research and the actual invention of a new technique or product; the lag between invention and the development and complete market acceptance of the new product; and its disappearance from the currently utilized stock of knowledge due to changes in external circumstances and the development of superior techniques or products by competitors (depreciation and obsolescence). There is some scattered evidence, based largely on questionnaire studies, that such lags are rather short in industry, where most of research expenditures are spent on development and applied topics, and where the private returns from R&D become obsolete much faster due to the erosion of a firm's specific monopoly position (Ariel Pakes and M. Schankerman, 1984).

While my models are written as if the main point of research expenditures is to increase the physical productivity of the firm's production process, most of the actual research in industry is devoted to the development of new products or processes to be sold and used outside the firm in question. Assuming that, on average, the outside world pays for these products what they are worth to it, using sales or value-added as the dependent variable does, in fact, capture the private returns to such research endeavours. However, the observed private returns may underestimate the social returns because, given the competitive structure of the particular industry, the firm is unlikely to appropriate all of these returns. On the other hand, part of the increase in the revenues of a particular firm may come at the expense of other firms, or from changes in the market power induced by the success of its research program. I cannot say much about the net impact of such forces on the basis of the data at hand. This would require a detailed comparison of the individual firm results with estimates based on industry and economy-wide returns to research, a topic beyond the scope of this project. But since expected private returns are a determinant of private investment flows into this activity, they are of some interest even if one cannot answer the social returns question unequivocally.

This framework can be extended to ask whether different types of R&D (private vs. federal, or basic vs. applied) are equally "potent" in generating productivity growth. One way of answering this question is to look at the "mix" of R&D expenditures and ask if it matters for the question at hand. Let there be two types of R&D expenditures, R_1 and R_2, and let us assume that the overall analysis is in terms of the logarithm of total R&D expenditures but that we believe that R_2 should have been weighted more, given a δ premium (or discount). That is, the right variable is

$$(2) \qquad R^* = R_1 + (1 + \delta)R_2 = R(1 + \delta s),$$

where $s = R_2/R$ is the "share" of R_2 in total $R = R_1 + R_2$. Then the $\alpha \log R^*$ term can be approximated by $\alpha \log R^* \simeq \alpha \log R + \alpha\delta s$. The sign and significance of the mix term s will give us some clue about the size and magnitude of the δ term.

A similar argument can be made also in the context of a growth-rate formulation. Let lower case letters denote growth rates. Then $r = (1 - s)r_1 + sr_2$ while $r^* = (1 - s)r_1 + (1 + \delta)sr_2$. If, as is mostly the case in our data, the growth rates of r_1 and r_2 are roughly equal, then $r^* = r(1 + \delta s)$, and again, the coefficient of the mix term s provides us with some information about the "premium" or "discount" on R_2 since αr^* can be approximated by

$$(3) \qquad \alpha r^* \simeq (\alpha + \delta\bar{s})r + (\alpha\bar{r}\delta)s .$$

Given the peculiarities of my data set—its unbalanced nature (many missing observations towards the beginning and end of the period), the availability of capital and value-added only for Census years, the desire to preserve comparability with the earlier study, and the difficulty of doing elaborate programming inside the Census Bureau, I focus primarily on two major dimensions of the data: levels (in 1967, 1972, and 1977) and growth rates, and eschew any attempt at a complete annual data analysis. The annual data are summarized by computing average growth rates for two subperiods 1957–65 (corresponding to the earlier study period) and 1966–77, based on regressions of the logarithms of the relevant variables on time trends (solving thereby the missing years problem within each of these subperiods).

In implementing such a framework of analysis one has to deal with several serious data problems: missing data, erroneous data and possible erroneous matches, and mergers. Except for R&D data, no special effort was made to replace missing values by various imputation procedures. It was my notion that the basic data set represents what the Census did collect, what we actually know, and that any imputation procedure should be done only in the context of a particular research project where its implications for the final analysis could be interpreted. As far as the R&D data are concerned, the Census used the shuttle nature of the original questionnaires to fill in many of the original blanks. To the extent that there remain missing values which are not due to the fact that the whole company is missing before or after some date, they were interpolated on the basis of the estimated growth rates (which require at least five good data points within each subperiod). For other variables, missing values were not imputed. It was not possible, within the constraints of this project, to develop optimal imputation procedures. This would have required several repeated passes at the original numbers. Instead, the analysis is based either on reduced "clean" samples or on "pairwise present" correlation coefficient matrices.

From an econometric point of view, we have to deal with the problem of firm effects (or firm-specific left-out variables) and the possibility that the relationships being estimated may not stay constant either across firms or across time. The first is handled by analyzing first differences or growth rates, transformations that eliminate any unchanging effects from the data. The second problem, the problem of differences across firms, is handled in part by calculating a measure of "partial" productivity growth $[BPT = y - (1 - \hat{\beta})l]$, using individual firm data on the share of labor in total costs. One can also estimate separate and different parameters for the various industry groupings and include some of the other variables available in the record which might distinguish one firm's environment and response pattern from another's (such as its specialization ratio, size, or vertical integration). The main hypothesis under investigation, that the returns to R&D investments may have declined over time, is tested both by comparing estimates based on the more recent data with the earlier results, and by allowing and testing for systematic changes in the estimated relationships between the three available cross sections.

Let us look now at the first set of substantive results. Table 4.2 reports the results of estimating cross-sectional production functions (equation (1)) separately for each Census year, adding to the standard capital and labor variables a measure of total R&D capital accumulated by the firm and two R&D mix variables: the fraction of total R&D that was spent on basic research and the fraction of accumulated R&D that had been financed privately. All the reported estimates allow for 18 to 20 (depending on the subsample) separate industry intercepts. Columns 1 and 3 report estimates that are based on the same number of firms and use the same dependent variables, differing only by the year of observation. Column 2 presents additional estimates for 1972 based on different sample and dependent variable definitions with the main intent being to show that the major conclusions are insensitive to such differences. There are three major points to be made about these estimates. The first is that the stock of R&D capital contributes significantly to the explanation of cross-sectional differences in productivity and there is little evidence of a decline in its coefficient over time.[2] There is a minor rise in the estimated coefficient from 1967

2. Here and subsequently, all statements about statistical "significance" should not be taken literally. Besides the usual issue of data mining clouding their interpretation, the "samples" analyzed come close to covering completely the relevant population. Tests of significance are used

Table 4.2 **NSF-Census Study: Cross-Sectional Production Functions, Log Value-Added Dependent Variable[a] U.S. Firms: 1967, 1972, 1977**

	(1)		(2)		(3)[b]	
Variables	1967	1972	1972	1972	1972	1977
ln Employment	.604	.622	.623	.586	.578	.611
	(.045)	(.046)	(.035)	(.038)	(.038)	(.039)
ln Capital Services	.224	.199	.161	.234	.254	.291
	(.041)	(.044)	(.032)	(.036)	(.036)	(.035)
ln R&D Stock (*db*)	.113	.135	.165	.126	.115	.089
	(.023)	(.026)	(.019)	(.019)	(.018)	(.017)
Basic Research (*BR*)	.396	.340	.274	.499	.517	.401
	(.240)	(.261)	(.215)	(.191)	(.189)	(.189)
Company-Financed	.190	.247	.068	.133	.138	.044
Research (*FP*)	(.097)	(.106)	(.100)	(.088)	(.088)	(.084)
N	386	386	652	491	491	491
SEE	.312	.336	.390	.312	.309	.290

Notes: ln Employment = log (total employment − employment of scientists and engineers); ln Capital Services = log of (depreciation plus interest on net assets plus machinery and equipment rentals); ln R&D Stock (*db*) = log of the "stock" of total R&D expenditures based on a 15 percent per year declining balance depreciation assumption; *BR* = basic research as a fraction of total R&D; 1972 in the 1977 equation, 1967 in 1967 and 1972. *FP* = fraction of R&D stock "private," company-financed R&D stock as a ratio to the total R&D stock, as of *t*. All equations include also a constant term and industry dummies. The number of industry dummies used depends on the data set and varies between 18 and 20. Standard errors are shown in parentheses.

[a]Value-added and materials used in research in 1967 and 1972.

[b]Value-added only.

to 1972 and a somewhat larger but not really significant decline from 1972 to 1977. Given this particular measure of R&D capital, based on a 15 percent per year declining balance depreciation formula (the results are insensitive to the particular formula used), the implied average (at the geometric mean of the sample) gross rate of return to R&D investment rises in a similar fashion from .51 in 1967 to .62 in 1972 (in col. 1) and falls from .39 in 1972 to .33 in 1977 (in col. 3). In either case the estimated rate of return is quite high and there does not appear to be any dramatic fall in it over time.

The second major finding is the significance and rather large size of the basic research coefficient. It seems to be the case that firms that spend a larger fraction of their R&D on basic research are more productive, have a higher level of output relative to their other measured inputs, including R&D capital, and that this effect has been relatively constant over time. If anything, it has risen rather than fallen over time. Using the formulation of equation (2) implies a very high premium on basic versus the rest, a $\hat{\delta}$ of between 2.5 to 4.5, a

here as a metric for discussing the relative fit of different versions of the model. In each case, the actual magnitude of the estimated coefficients is of more interest than their precise "statistical significance."

several hundred percent premium on basic research. Before I explore the implications of this result, I want to examine other dimensions of these data and see whether similar effects can be observed there too.

The last major result of interest is the significant positive coefficient on the privately vs. federally financed R&D mix variable. This variable is of most import for the older more established firms in subsample 4 (Table 4.1) but its sign is consistent throughout, indicating a positive premium on privately financed R&D, or equivalently a discount as far as federally financed expenditures are concerned. Here the implied premium is smaller, between 50 and 180 percent, but still quite large.

All the above results were based on cross-sectional level regressions that are subject to a variety of biases, the main one being the possibility that "rich" successful firms are both more productive and can afford to spend more of their own money on such luxuries as R&D and especially the basic variety. One can reduce somewhat the possibility of this type of bias by focusing on firm-growth rates, the changes that occurred, rather than on their levels. To the extent that firms have idiosyncratic productivity coefficients that may be also correlated with their accumulated R&D levels, considering growth rates is equivalent to doing a "within" firms analysis, one that eliminates such fixed effects from the analysis. The next two tables present, therefore, the results of analyzing the growth in the partial productivity of these same firms during the whole 1966–77 period.

Table 4.3 presents the results of estimating partial productivity equations in

Table 4.3 Growth Rate of Partial Productivity, 1966–77

Variables	$N = 911$		$N = 652$ (with industry dummies)		
Constant	.019	.009	.012	—	—
BTRD 6677	.107		.117	.119	
	(.014)		(.017)	(.016)	
BCRD 6677		.095			.106
		(.014)			(.015)
*BR*72	.056	.056	.059	.035	.034
	(.017)	(.017)	(.019)	(.018)	(.018)
*FP*72	.011	.019	.017	.022	.030
	(.005)	(.005)	(.006)	(.007)	(.007)
SEE	.0383	.0384	.0337	.0305	.0307

Notes: Dependent variable: *BPT* 6677 = trend growth rate of deflated sales minus the trend growth of total employment multiplied by the share of payroll in total sales. *BTRD* = trend growth of deflated total R&D expenditures; *BCRD* = same for company-financed R&D expenditures; *BR* = basic research expenditures as a fraction of total research expenditures; *FP* = ratio of company-financed R&D stock to total; *SEE* = residual standard error. All equations contain also a term reflecting the variance of R&D and terms representing the growth of physical capital: age composition and depreciation as of 1972.

the largest possible sample for which 1966–77 growth rates were computable ($N = 911$) and in the subsample with a successful 1972 Census match. Here again we find my three main results confirmed: the R&D growth term and the two mix variables, the basic research ratio, and the fraction of research financed privately all contribute significantly to the explanation of productivity growth.

On the assumption that the growth rate in the stock of R&D is roughly proportional to the growth in deflated R&D itself, the coefficient of *BTRD* should be estimating the same number as the coefficient of the R&D stock variable in Table 4.2. The results are in fact surprisingly close: about .12 in Table 4.3 as against .09 to .17 in Table 4.2. Moreover, there seems to have been no decline in this coefficient relative to the earlier 1957–65 period. In my previous study (1980a), I estimated the same coefficient to be .073. In the current replication and extension of this sample a similar equation for 1957–65 yields a *BTRD* coefficient of .086. Thus, if anything, the coefficient of R&D went up between the early 1960s and the early 1970s.

The second major finding of interest is the positive and significant basic research coefficient. It is hard to interpret its magnitude since the approximation outlined in equation (3) breaks down when the average growth rate of deflated R&D and of basic R&D is close to zero or negative. Consider, however, the following illustrative calculation. Raising the *BR* ratio by one standard deviation, from .026 to .097 at the mean, would increase the rate of growth of partial productivity by close to half a percent per year ($.071 \times .059 = .0042$). This same increase would raise the growth of total R&D by .107 for one year and would contribute a once-and-for-all increase in the level of productivity of .0125. Discounting the more "permanent" effect of basic research by a real interest rate of .05 yields an "equivalent" one-year effect of .084, or a 7 to 1 ratio in favor of basic research! If one allows for industry dummies which in this formulation represent separate industry trend rates of disembodied technical change, the effect of basic research is cut by about 50 percent, implying perhaps that a significant fraction of the estimated effect comes from spillovers that diffuse throughout the industry. Note that it is the only coefficient that is affected substantively when separate industry dummies are allowed for. Nevertheless, even a 3.2 to 1 ratio is quite high!

The third finding is the significant positive premium on company-financed R&D. Here too the implied premia are quite high, but given that the mix variable is defined in terms of stocks rather than flows, the calculations are more cumbersome. Consider starting from a zero growth position and a .7 ratio of private to total R&D stock. To move this fraction from .7 to .75, one would need to raise the private stock by 29 percent and the overall stock by 20 percent (without reducing absolutely the stock of federally financed R&D capital). There are different possible investment paths that would achieve this goal and would have somewhat different present value consequences. If one roughly doubled the rate of privately financed R&D expenditures, from the previous replacement level of .105 (.7 × .15) to .205, one could achieve this target in slightly over two years. Ignoring discounting, this would lead to a once-and-for-all growth in productivity of .024, due to the growth in the total stock of R&D *and* a .0011 permanent increase in the rate of growth due to the shift of the fraction private ratio from .7 to .75. The present value of this second term is about .022, or of the same order of magnitude as the first term. That is, raising the stock of R&D by 20 percent but shifting it all into the private component doubles the effect of such dollars.

There are problems, however, with such an interpretation. If private R&D expenditures contribute more to productivity growth, one might have thought that when they are substituted for the total R&D growth measure, they might fit better and also have a higher coefficient. But that is not the case as can be seen from the results presented in columns 2 and 5 of Table 4.4. The total R&D measure does a little bit better both in terms of fit and in the overall size of its coefficient, implying that the contribution of federal dollars is not zero. That is perhaps what one should expect. Most of the direct output of federal research dollars is "sold" back to the government at "cost plus" and is unlikely to show up as an increase in the firm's own productivity. Thus all that one could expect to measure here are the within-firm spillover effects of such expenditures. What we may be detecting is that such effects are indeed present and positive, but we should not have expected them to be of the same order of magnitude as would be the case for the firm's own investments in improving its productivity or profitability.

There are a number of econometric questions that can be raised about the robustness and sensitivity of such results. I will discuss only a few of these here. The most obvious question arises from the fact that even though I allowed, in the growth rates version, for separate firm intercepts and different industry trends, I am still assuming common R&D and the conventional capital

Table 4.4 **Growth Rate of Partial Productivity, by Industry, 1966–77 (Matrix 6, Total N = 991)**

Coefficients of	Coefficients by the Estimated t-Ratio			
	<−1.5	−1.5–0	0–1.5	1.5+
BTRD		2	7	10:Miscellaneous, Industrial Chemicals, Drugs, Stone & Glass, Machinery, Electronics, Electrical Equipment, Transportation Equipment, Scientific Instruments, Non-Manufacturing
*BR*72		5	8	6:Wood & Paper, Other Chemicals, Oil, Machinery, Aircraft, Non-Manufacturing
*FP*72	2	6	7	4:Oil, Rubber, Electronics, Aircraft

Notes: All equations contain also a term reflecting the variance of R&D and terms representing the growth of physical capital: age composition and depreciation as of 1972.

coefficients across rather different industries. This is done from necessity rather than as a virtue. Estimating the same models industry by industry reduces the sample sizes drastically and raises greatly the relative noise level, making it rather hard to interpret the resulting estimates. Nevertheless, these estimates, which are summarized in Table 4.4, are quite consistent with the earlier story: 17 out of the separately estimated 19 coefficients for the R&D growth variable are positive and more than half of them are statistically significant at conventional significance levels. Similarly, the coefficients of the basic research ratio variable are positive in 14 of my 19 industries and significant in over a third of them. The fraction private variable is less robust to the division of the sample into industries, with more than half of the coefficients still positive, but only 4 of them are statistically significant within particular industries. Two of these industries are indeed the ones where one would expect to find such an effect, aircraft and electronics, industries where the bulk of federal monies is spent. Nevertheless, it seems that the effect that is being caught by the fraction private variable has an important industry component, something that had been already noted in my earlier study (1980a), as does also the effect associated with the basic research variable, though to a lesser extent.

A number of other versions were computed using the growth in capital services rather than the depreciation and age composition variables that had been used to keep the results comparable to the earlier study, and the growth in R&D "capital" rather than the flow (and also different definitions of such capital). I also estimated versions using the "intensity" form for the R&D variable, to make it more comparable to other studies in the literature (my paper with Lichtenberg, 1984; Mansfield, 1980; and others).[3] By and large the results of these alternatives were somewhat weaker but not substantively different. Perhaps the most interesting alternative estimate is the intensity version using the growth of capital between 1967 and 1972 as its capital measure:

$$
\begin{aligned}
BPT6677 &= \ldots .243ACRS + .045ABR + .180DLCS \\
&\qquad\quad (.069) \qquad\quad (.024) \qquad\quad (.130) \\
SEE &= .0316 \\
&\text{(Subsample 4)}
\end{aligned}
\tag{4}
$$

where *ACRS* is the average company R&D to sales ratio, averaged over 1967 and 1972, *ABR* is a similar average basic to total R&D ratio, and *DLCS* is the rate of growth in deflated capital services between 1967 and 1972. This version

3. The intensity version uses the fact that $\alpha = (\partial Q/\partial K)\, K/Q$ and reexpresses $\alpha\dot{K}/K$ as $\rho[R/Q]$, where $\rho = \partial Q/\partial K$ is the marginal product (gross rate of return) of R&D capital and it has been assumed that $\dot{K} = R - \delta K \simeq R$, i.e., either $\delta \sim 0$ (no depreciation) and/or initial K very small. This formulation has the advantage that it does not impose the assumption of a constant *elasticity* across different firms, replacing it instead by the, possibly more plausible, assumption of the constancy of rate of return.

is closest in form to the equation estimated by Mansfield on much smaller samples. The basic results are similar, however. Basic R&D is a significant contributor to productivity growth with an implied basic to company premium of about 5 to 1 (given an average R&D to sales ratio of .035).

The final set of results to be presented here, in Table 4.5, relate to the relative profitability of our firms in 1972 and 1977. The dependent variable, *GRR*, is the ratio of gross profits (value-added minus labor costs and plus R&D) to total gross fixed assets. The independent variables include the ratio of R&D capital (undepreciated) to total fixed assets and our ubiquitous R&D mix variables: the basic research and fraction private ratios. Even though the dependent variable is quite different, the overall results are rather similar to the earlier ones. The R&D capital variable is positive and almost always statistically significant though its coefficient is a bit low if it is to be interpreted as a rate of return to it. The basic research variable is both large and significant though possibly too large to be credible. Given that the ratio of total R&D capital to total fixed assets is only about .05 on average, the 1972 coefficients imply a δ of about 30 to 60. The fraction private ratio also contributes positively to profitability but its effect largely disappears once industry differences are allowed for. The results for 1977 are weaker than those for 1972, the residual variance is significantly higher, but they too suggest the importance of basic research even in this context.

Table 4.5 Gross Profit Rate Regressions
***GRR* = (Value-Added-Payrolls + R&D)/Gross Assets**

		Coefficients of			
Dependent Variable and Sample Size	Constant	R&D Capital to Total Fixed Assets Ratio	Basic R&D Ratio	Fraction Private	*SEE*
*GRR*72					
N = 652 (a)	.144	.088	.344	.107	.262
	(.049)	(.012)	(.144)	(.048)	
(b)		.060	.187	−.012	.237
		(.013)	(.138)	(.052)	
N = 491 (a)	.117	.080	.514	.154	.264
	(.052)	(.013)	(.139)	(.051)	
(b)		.061	.366	.074	.227
		(.015)	(.138)	(.057)	
*GRR*77					
N = 491 (a)	.341	.031	.402	.033	.313
	(.064)	(.019)	(.187)	(.068)	
(b)		.004	.261	−.028	.292
		(.022)	(.187)	(.077)	

Notes: (a) Regressions do not contain industry dummies; (b) do.

A similar analysis was performed using an estimate of the net rate of return as the dependent variable, subtracting depreciation from the numerator of *GRR* and using a net stock concept for the denominator and also in the definition of the R&D capital variable. While the fit was significantly worse when using this definition of the dependent variable, the overall results were rather similar. The net return version was also available for 1967 and the results using it indicate a relatively constant and significant coefficient for the basic research ratio while the coefficient of the total R&D stock rises from 1967 to 1972 and then falls again in 1977 (from .11 to .16 and down to .06). It is doubtful whether these fluctuations represent real trends or, more likely, reflect the larger noise level in the 1977 data and the changing composition of these samples. In any case, the profitability regressions are consistent with the productivity level and productivity growth rate based results described earlier (Tables 4.2, 4.3, and 4.4).

4.3 Discussion and Summary

There are three major findings in this paper: R&D contributed positively to productivity growth and seems to have earned a relatively high rate of return; basic research appears to be more important as a productivity determinant than other types of R&D; and privately financed R&D expenditures are more effective, at the firm level, than federally financed ones. These findings are not entirely new. The first finding has been documented in a number of earlier studies (see my 1980a,b papers; my article with Mairesse, 1984; A. N. Link, 1981a; and others). What is new in this paper in this regard is a confirmation of this finding on a much larger and more recent data set. It also presents evidence for the view that this effect has not declined significantly in recent years, in spite of the overall slowdown in productivity growth and the general worry about a possible exhaustion of technological opportunities.[4]

The evidence for a "premium" on basic research is much more scarce. The major previous paper suggesting this type of a result is Mansfield (1980), which uses aggregate data for 20 industries for 1948–66 and data for 16 firms during 1960–76, and finds a significant premium on basic research, on the order of 2 to 1 at the industry level and 16 to 1 at the firm level. (See also Link, 1981b, for similar results for 1973–78 based on data for 55 firms.) In this paper I get similar though somewhat smaller effects at the firm level, using a much larger and more representative sample. I also find that differences in levels of

4. The finding that the coefficients in a logarithmic regression have not declined over time does not dispose of the possibility that there could have been an overall loss in accumulated knowledge capital due to accelerated obsolescence. A proportional decline in the effectiveness of past capital or in the rate that R&D is converted into new knowledge capital need not show up as decline in the slope coefficient, it would get absorbed into the shifting constant. Disproportionate shifts should, however, have an impact on the estimated slope coefficient. Also, a pure obsolescence shock to old knowledge capital would have called forth an increase in the rate of R&D expenditures, something which has not been observed in the data. I am indebted to M. N. Baily for this point.

productivity and profitability are related to differences in the basic research intensity of firms.

Such findings are always subject to a variety of econometric and substantive reservations. In this context the two major related issues are simultaneity and the question of how major divergences in private rates of return persist for such long periods. It is possible to argue that it is not R&D, or its basic research component, that causes firm "success" as measured by productivity and profitability, but rather that success allows firms to indulge in these types of luxury pursuits. It is difficult to argue about causality on the basis of what are essentially correlational data. It is possible to use simultaneous equation techniques to estimate such models, but then the argument shifts to the validity of the exogeneity assumption for the particular instruments. In the context of my specific data set, it is hard to think of any valid instruments except for possibly lagged values of the same variables, which raises some problems of its own. The best evidence for the notion that these results are not entirely spurious is provided by the growth rates where the individual firm levels are partialed out of the analysis. But, here too, one could argue about the impact of common unanticipated "luck" elements. Unfortunately, it is unlikely that one could use lagged growth rates as instruments, since there is very little correlation in growth rates over time at the firm level. While an attempt will be made in further work with these data to estimate more extended simultaneous equations versions of such models, I am not too optimistic as to what can be accomplished in this regard. The evidence presented here should not be interpreted as "proving" that R&D, and especially its basic component, are important for productivity growth but rather as presenting some prima facie evidence in support of such an interpretation. In this sense it is an exercise in economic rhetoric (Donald McCloskey, 1983).

It is even more difficult to respond to the theoretical a priori argument that such results cannot be true since they imply widely differing rates of return to different activities under the control of the same firm. One's response to this depends on one's views as to the prevalence of equilibria in the economy. While it is likely that major divergences in rates of return are eliminated or reduced in the long run, the relevant runs can be quite long. R&D as a major component of firm activity was undergoing a diffusion process in the 1950s and 1960s and may not have reached full equilibrium even by the end of our period. This may be especially true of the basic research component where the risks are much greater and the uncertainty introduced by changing government policies and the changing economic environment make it quite difficult to decide what is the right level for it.

A somewhat different version of this argument would claim that the world is indeed in approximate equilibrium but that different firms face different opportunities for doing research, basic or otherwise, are in different ecological niches, and hence have different coefficients in their "production functions." This would explain why different firms are observed to spend different amounts on R&D while actually earning about the same rate of return on it. When a constant coefficients production function is fit to such data, it will fit because it is approximating a market equilibrium relation. If the level of R&D invested were independent of the coefficient, then such a function would just reproduce its average share and not produce any evidence of excess returns. But if, as is reasonable, R&D is invested optimally with firms which have better opportunities, higher coefficients, investing more, this will induce a positive correlation between R&D and its individual coefficient and lead to an upward bias in the estimated "average" coefficient.[5] The resulting "larger" coefficient, larger than the observed factor share, will be interpreted, wrongly, as implying a higher rate of return than is actually prevailing at the individual level.

This argument may be recognized as a version of the earlier attacks on the Cobb-Douglas production function combined with a random coefficients interpretation of the same phenomenon. In its extreme form it is testable. Since there are time-series data available for individual firms, one could try to estimate individual firm parameters and check whether they are in fact distributed as is predicted by this particular argument. While individual parameters are unlikely to be well estimated, given the relative shortness of the available time-series, the parameters of the distribution of such coefficients might be estimable with more precision. I intend to pursue this possibility in future work.

To restate again the major points of the paper: a newly available body of data on all the major firms performing R&D in the United States has been examined and evidence has been presented for the proposition that R&D contributes significantly to productivity growth, that the basic research component of it does so even more strongly, and that privately financed R&D expenditures have a significantly larger effect on private productivity and profitability than federally financed R&D. These findings are open to a number of reservations. Nevertheless, they do raise the issue that the overall slowdown in the growth of R&D and the absolute decline in basic research in industry which occurred in the 1970s may turn out to have been very costly to the economy in terms of foregone growth opportunities.

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5. A positive correlation is not enough, by itself, for a positive bias. The weight of an individual firm slope coefficient in the cross-sectional estimate is proportional to the *square* of the deviation of R&D stock from its mean. A positive correlation between levels does not translate itself directly into a positive correlation between the level of one variable and the square of the other, except for certain skewed distributions. Since we do not observe the individual coefficients directly, it is rather difficult to check out this conjecture.

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