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6 Productivity Growth and R&D at the Business Level: Results from the PIMS Data Base

The recent slowdown in productivity growth in the United States and elsewhere has increased interest in understanding its determinants. Among the determinants commanding attention have been expenditures for research and development. R&D investment has attracted attention because a slowdown in its growth seemed to coincide with the productivity slowdown, and because earlier studies of the R&D-productivity connection had found R&D to be an important determinant of productivity growth. Recent work on R&D and productivity growth, however, presents a relatively mixed picture. While studies on 1950s and 1960s data generally found positive effects, productivity equations for the 1970s found the coefficient alternately collapsing (Griliches 1980; Agnew and Wise 1978; Scherer 1981; Terleckyj 1980) and reviving (Griliches and Lichtenberg 1984; Scherer 1981), depending on the data used and, in particular, on the level of aggregation. Where disaggregated data were explored, a relatively sizeable effect of R&D was found, even in the turbulent 1970s.

This paper presents the results of a study of productivity growth and R&D in the 1970s using data on narrowly defined "business units" within a firm. The principal focus of the analysis is estimation of the productivity of R&D at the margin. Estimates are developed under different assumptions about technology, industry effects, and changes in the return to R&D over time. Our R&D data are classified into process and product expenditures, and we examine the effect of proprietary technology and technological opportunity on R&D productivity.

The results reported below suggest a significant relationship between R&D and the growth of productivity; in versions using total factor productivity as the

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dependent variable, the estimated marginal product or rate of return is about 18 percent. There is no evidence in these data of a deterioration in the productivity of R&D in the 1970s. Irrespective of model specification, trends in the R&D coefficient are substantively and statistically insignificant. We also find some evidence that, all else equal, a shift in the mix toward more product R&D lowers the measured rate of growth of productivity, and that R&D has its biggest effect on productivity in those businesses where major technical changes have occurred within the recent past.

The paper has three parts. We discuss the data used and present summary information about our key variables in section 6.1. Particular attention is paid to the reported price indexes. Estimates of price changes in the PIMS data are compared with estimates based on government surveys. Section 6.2 sets out the analytical framework and presents estimates of the effect of R&D on productivity under several model specifications. The paper concludes in section 6.3 with a brief summary and some suggestions for further work.

6.1 The Data Set

The data we use are drawn from the PIMS project of the Strategic Planning Institute (SPI).[1] The Institute is composed of over 1,500 member companies which participate in the project by supplying annual data on individual businesses within the company. Our sample covers 924 U.S. manufacturing businesses over the period 1970–80.

A "business" in the PIMS lexicon is a unit of a firm "selling a distinct set of products to an identifiable set of customers in competition with a well-defined set of competitors." Businesses tend to be synonymous with operating divisions of a company but may be defined in terms of product lines within divisions. In addition to annual income statements and balance sheets, each business provides information on several measures of market structure, technology, previous competitive experience, and competitive strategy. Along with its panel structure and level of detail, the richness of the PIMS data set makes it a potentially valuable source of information on the determinants and impact of R&D.

But richness has its price. Several aspects of the data must be kept in mind when interpreting the evidence presented below. In the first place, we are not dealing here with typical or representative firms. The companies in the project tend to be large, diversified corporations; many are found in the *Fortune* 500; and almost all of them are found in the *Fortune* 1,000. The analysis thus deals with the impact of R&D on productivity among firms that may not be representative of all firms in a given sector, but which probably account for a significant fraction of the assets and people employed.

1. A description of the PIMS data can be found in Schoeffler (1977). For an analysis of R&D and profitability using the PIMS data, see Ravenscraft and Scherer (1981).

The unit of observation is a further problem. Although SPI provides guidelines for defining "business units," the choice is left to the company and will depend on the availability of data and the company's assessment of the usefulness of the definition.[2] In a related fashion, much of the structural data is subject to the company's assessments and perceptions. Of course, a good deal of the information requested by SPI is available through accounting systems and is subject to uniformity of definition and guidelines developed and imposed by SPI. But variables, like the number of competitors or the relative quality of the business's products, depend to some extent on the respondent's perceptions.

Finally, the self-reported character of the data and their use in comparative modeling raise questions about their quality and integrity. Two considerations suggest that the quality of the data is reasonably high. First, the information requested is of value to the business itself (e.g., its market share), and it seems reasonable to suppose that the firm is in a position to know and has expended effort to acquire accurate data. Second, a firm's participation in the project is motivated by a desire to use the data in the strategic planning models developed by SPI. Considerable effort is made to preserve confidentiality and ensure quality: only the firms themselves have access to their own data; sensitive variables (e.g., profits) are only reported in disguised or ratio form; analysts at SPI run the data through an elaborate procedure to check for consistency, and gross errors are followed up with the company.

6.1.1 Major Variables

The annual income statement and balance sheet provided by each firm can be used to construct measures of productivity, R&D, and capital. We use sales, deflated by an index of product prices, as the basic measure of output. Although available information permits calculation of value added, we found that treating materials as a separate factor of production fit the data much better. The output price index and an index of materials prices are provided by the business under guidelines set forth by SPI. The guidelines define the relevant concept of output price as a weighted average of the business's selling prices, holding the mix of products constant. Since the quality of the output and productivity series depends on the quality of the output price indexes, they are examined below in more detail.

Information on labor input is limited. The only variable available to us is the number of employees, and that is only available on a disguised basis and thus can only be used in ratio form. There are no data on hours per employee, nor are the data broken down by occupation or type of employment. Output per employee and capital-labor ratios are defined for all employees, including sales and managerial personnel, as well as those engaged in R&D activities and

2. Definition of a business as developed in the PIMS guidelines is based on the concept of a "strategic business unit." This concept is spelled out in more detail in Abell and Hammond (1979).

production. These variables are not adjusted for differences in quality, since no wage data or data on education or other characteristics are available.

Estimates of the real stock of capital are derived from information on the firm's balance sheet and annual investment. The value of plant and equipment in the firm is reported at historical cost, but each firm provides an estimate of the replacement value of gross plant and equipment in the initial year of its participation in the survey. This gives an initial capital stock value in current prices. Since firms may enter the sample in different years, we restate the initial value in current prices into constant (1972) dollars using the deflator for business fixed investment (BFI) from the National Income and Product Accounts. Subsequent investment in plant and equipment is deflated by the BFI price index and added to the initial year stock. The investment series we use is net of retirements, but we have not subtracted out reported depreciation.[3] To provide a comparative perspective, we shall estimate the models using gross book value of capital as well as the stock of capital adjusted for inflation as described above.

As with most data sets, information on R&D comes in the form of current spending. Expenditures on research and development are treated as an expense in the PIMS accounting system and are, therefore, reported in the income statement. Businesses are asked to include in this category all expenses (material, labor, etc.) incurred to improve existing products or to develop new products, and all expenses to improve the efficiency of the manufacturing process. Total R&D expenditures are thus classified into product and process categories. How that split is implemented, however, is left to the business to decide. All R&D expenses are specific to the business and exclude charges for research and development done in a central corporate facility. They may, however, include expenses shared with other businesses but conducted below the corporate level.

Table 6.1 presents definitions, means, and standard deviations of the basic variables used in the analysis. The sample covers 924 businesses, with a total of 4,146 observations; not all firms are present in each year, so the design of the sample is unbalanced. Data on real sales, materials, and capital per employee show a substantial amount of variability around relatively high average rates of growth. In real terms, sales per employee grew at an annual rate of 4 percent in these data, while capital and materials per person grew at rates between 3.5 and 4.0 percent. The data on newness of the capital stock (ratio of net to gross book value) suggest that, on average, productivity growth occurred during a period in which the capital stock was aging.

3. The nominal investment series is calculated as the difference in the gross book value of plant and equipment. It thus reflects both gross investment and retirements. Estimates of real capital can be obtained in other ways. One possibility is to estimate the age of capital using the ratio of accumulated depreciation to annual depreciation, and then to adjust current book values based on changes in the BFI deflator since the year the average piece of capital (determined by the age calculation) was purchased. For an example of this approach, see Griliches and Mairesse 1984. Their results, as well as our own estimates reported below, suggest that the R&D estimates are relatively insensitive to adjustments of this sort.

Table 6.1 **Means and Standard Deviations U.S. Manufacturing Businesses, PIMS Data Base, 1971–80**

Variable	Definition	Mean	Std. Dev.
(1) Rates of Growth (in percent):			
$(s - l)$	real sales per employee	3.95	17.33
p	output price index	7.40	9.10
$(m - l)$	real purchases per employee	3.93	22.31
p_m	materials price index	9.17	12.42
$(g - l)$	gross book value of plant and equipment per employee	7.32	19.22
$(c - l)$	gross plant and equipment per employee in 1972 $	3.55	17.00
util	rate of capacity utilization	2.71	16.62
new	ratio of net to gross book value of plant and equipment	−1.15	12.54
(2) R&D Variables (in percent):			
$RQ(-1)$	ratio of total R&D expenses to average of current sales and sales lagged one period	2.21	3.76
RMIX	ratio of product R&D expenses to total R&D expenses	65.49	29.94
(3) Proprietary Technology and Technological Opportunity:			
DPROD	= 1 if business derives significant benefit from proprietary products (patents etc.) = 0 otherwise	0.21	—
DPROC	= 1 if business derives significant benefit from proprietary processes (patents etc.) = 0 otherwise	0.21	—
DTECH	= 1 if there have been major technological changes in product or process of the business or its major competitors in last eight years = 0 otherwise	0.28	—

Variables measuring R&D intensity and mix are listed in part 2 of table 6.1. These data are of a reasonable order of magnitude and imply that the businesses in the sample cover a wide range of R&D intensities. As in data collected at other levels of aggegation, the majority of R&D (65 percent) is devoted to improving old or developing new products. Although the sample covers most of the two-digit industries, almost half of the observations are from businesses in chemicals, electrical and nonelectrical machinery, and instruments.

We have used the PIMS data to calculate R&D intensity for these two-digit industries, as well as for primary and fabricated metal products, and compared them to data published by the National Science Foundation (NSF). This comparison, presented in table 6.2, shows the same ranking of industries by R&D intensity in the two data sets. Since the NSF is a company-based data set, and since the mix of subindustries within the two-digit industries may not be identical, differences in the R&D-to-sales ratio in the two series are to be expected. But the two sources yield intensity estimates that are quite similar. Only in machinery (SIC 35) does a sizeable discrepancy emerge.

We make no attempt to estimate the stock of R&D capital, but rather use R&D intensity to capture the effects of R&D on productivity. To allow for lagged effects and to break any spurious correlation induced by the presence of lagged output as an independent variable, we define R&D intensity as:

$$RQ(-1) = \frac{R_{-1}}{\frac{1}{2}(S + S_{-1})},$$

where R_{-1} is R&D expenditure in the previous period, and S indicates total sales. Other measures, including R&D intensity lagged one and two periods, and an instrumental variable procedure, had no effect on the results. We shall report only the estimates with $RQ(-1)$.

Part 3 of table 6.1 provides information on three variables that we use as indicators of previous technical activity. The first two indicate whether the business "derives significant benefit" from proprietary products or processes, either through patents or what the SPI guidelines call "trade secrets." The last variable indicates whether "major" technological change (either product or process) had occurred in the business or in its major competitors in the last eight years. These questions are asked only once (when the business enters the PIMS project) so that the dummy variables are constant over time. The data suggest that a sizeable fraction of the businesses have carried out R&D projects that have led to patents or some other form of proprietary products or processes. An issue we examine below is whether R&D capability defined in this way affects the current connection between R&D investments and productivity.

The mean growth rates of the basic variables are of a reasonable order of magnitude, but a somewhat more detailed look at the data, particularly at the

Table 6.2 **R&D Expenditures as a Percent of Sales in PIMS and NSF Data[a] for Selected Two-Digit Industries, 1974**

Industries (SIC)	PIMS	NSF
Chemicals (28)	2.8	3.0
Primary metals (33)	0.5	0.5
Fabricated metal prod. (34)	1.3	1.1
Machinery (35)	2.0	3.8
Electrical equipment (36)	3.5	3.5[b]
Instruments (38)	4.8	5.2

Source: NSF = National Science Foundation; PIMS = Calculated from PIMS data base.

[a]NSF data pertain to company expenditures on R&D; the PIMS data pertain to business level R&D, excluding R&D performed in corporate research laboratories.

[b]The NSF data for electrical equipment include data on communication (SIC 48).

output price series, seems in order. Although our focus is productivity, the measures of output underlying the analysis are only as good as the price indexes used to deflate nominal sales. A full-scale analysis of the data is beyond the scope of this paper, but we can provide some perspective by comparing rates of change of prices in the PIMS data with those found in the statistics published by the government. To do that we have focused on price changes in a group of industries where the number of observations available in the PIMS data set is sufficient to justify comparison with the published figures.

Table 6.3 presents annual rates of price change for nine two-digit SIC industries over the period 1971–79. Each cell in the table contains three entries. The first is the percentage change in the two-digit industry deflator calculated by the Bureau of Economic Analysis as part of the National Income and Product Accounts. The second entry is the average percentage change in the price indexes of PIMS firms in the corresponding two-digit industry. The last number is the number of PIMS firms in the industry in that year. The comparisons in table 6.2 are necessarily rough. Because the mix of four-digit industries underlying the PIMS two-digit calculations is different than the mix used in the BEA calculations, it is not reasonable to expect the two sources to yield identical estimates. However, to the extent that similar economic forces affect the constituent four-digit industries in similar ways, a two-digit level comparison should give us some idea of comparability.

Perhaps the most noticeable aspect of the BEA/PIMS comparison in table 6.3 is the similar pattern of change over time. Both data sets generally show small changes in prices in the first three years, followed by an explosion in 1974–75, with rates of price increases running as high as 25–30 percent in some industries. In the latter part of the period, the rate of change is once again much smaller, although higher than the rates found at the beginning of the decade.

Amidst this broad pattern of similarity there are clear differences between the published data and the data from PIMS. In most of the industries, for example, the 1974–75 explosion in prices shows up earlier in the PIMS data, but lasts longer in the BEA estimates.[4] A comparison of the sums of the rates of change in the two years (1974–75) yields values much closer together than comparisons of the years taken individually. Even before the oil shock and the expiration of controls, the two data sets show different patterns in some years in several industries. In fact, the comparisons before the oil shock are much more diverse than those made in the 1976–79 period. Although differences are present in the latter period, the large discrepancies found in the 1971–74 period are less frequent. This pattern may reflect the influence of wage-price controls on reporting practices or the different sources of inflationary pressure in the two periods.

4. The use of these data to deflate industry level output would change the estimated pattern of the productivity slowdown quite a bit. It would imply a much slower rise in the 1971–73 period and much less of a fall in 1975.

Table 6.3 **Comparison of Rates of Price Change in the PIMS Data Set and the National Income Accounts for Selected Two-Digit Manufacturing Industries**

Industry (SIC)	Data Set	1971	1972	1973	1974	1975	1976	1977	1978	1979
(1) Food (20)	BEA	1.5	−4.4	−7.4	15.4	22.7	−2.5	6.6	5.4	4.0
	PIMS	4.0	4.3	9.5	18.5	13.9	2.6	4.5	6.6	11.6
	N	29	35	41	49	40	33	27	17	11
(2) Chemicals (28)	BEA	1.1	−.2	−.8	11.0	12.4	4.2	2.8	4.5	2.7
	PIMS	−0.5	0.2	5.3	23.2	16.0	4.7	5.2	6.0	11.0
	N	75	89	108	95	94	91	55	36	15
(3) Rubber and plastics (30)	BEA	3.2	1.4	−1.0	6.9	9.5	4.9	5.3	4.4	4.3
	PIM	−0.7	−0.6	1.5	18.3	8.2	3.5	4.4	5.6	4.6
	N	22	29	37	46	43	32	21	17	12
(4) Stone, clay, and glass (32)	BEA	9.1	3.2	2.0	6.8	13.5	7.0	8.5	10.0	5.8
	PIMS	3.6	3.9	3.8	15.2	14.4	7.8	7.7	8.1	4.7
	N	15	23	30	36	36	38	34	22	7
(5) Primary metals (33)	BEA	3.1	8.6	−1.8	24.5	20.2	2.8	8.5	9.1	10.9
	PIM	0.5	2.3	10.3	29.2	12.4	2.0	5.2	9.7	9.4
	N	13	16	29	28	32	31	31	26	7
(6) Fabricated metals (34)	BEA	7.3	3.3	3.1	15.9	19.2	1.4	4.8	6.9	5.5
	PIMS	5.5	4.8	6.2	17.1	9.6	6.0	6.3	7.6	9.1
	N	12	25	42	56	63	57	49	36	34
(7) Nonelectrical machinery (35)	BEA	3.7	0.9	1.1	5.6	17.8	3.2	7.3	7.0	6.2
	PIMS	4.9	3.5	5.5	13.7	10.3	6.9	7.2	7.0	7.4
	N	42	60	84	95	100	91	71	45	23
(8) Electrical equipment (36)	BEA	3.0	−0.2	−0.3	4.8	12.5	3.0	5.1	3.8	6.7
	PIMS	0.7	1.4	2.3	12.7	8.7	5.4	5.2	6.2	8.5
	N	51	67	78	62	62	61	53	34	26
(9) Instruments (38)	BEA	1.4	−0.2	−0.6	−.08	9.0	6.2	1.7	6.5	4.0
	PIMS	1.1	2.0	3.2	9.4	8.3	4.9	5.4	4.1	5.3
	N	21	27	31	33	41	41	30	15	7

Source: BEA = Bureau of Economic Analysis, unpublished data, National Income and Product Accounts; PIMS = SPI/PIMS data set.

6.2 Empirical Analysis

The connection between R&D and productivity growth is studied in the context of a fairly conventional model. In its simplest form, output (Q) of the ith business at time t is assumed to be a function of the stock of capital (C), the number of employees (L), accumulated investment in R&D (K), and a factor accounting for disembodied technical change ($Ae^{\lambda t}$), as in

$$Q_{it} = Ae^{\lambda t}Q(K_{it},\ L_{it},\ C_{it}). \tag{1}$$

It is standard procedure to assume that K_{it} can be represented by a distributed lag of past investments in R&D with the weights presumed to depend on the way in which past activities affect the current state of technical knowledge.

Assuming the production function is Cobb-Douglas and separable in R&D, we can totally differentiate (1) and rearrange terms to derive an expression in terms of rates of growth:

$$q_i = \lambda + \gamma k_i + \alpha c_i + (1 - \alpha)\ell_i, \tag{2}$$

where γ and α are output elasticities with respect to R&D and capital, and lowercase letters have been used to indicate relative rates of growth of their uppercase counterparts (e.g., $k = (dK/dt)/K$). Note that we have assumed constant returns to scale with respect to the conventional measures of capital and labor. Rearranging terms yields a productivity equation:

$$(q - \ell)_i = \lambda + \gamma k_i + \alpha(c - \ell)_i, \tag{3}$$

Where $(q - \ell)_i$ is the growth rate of labor productivity, and $(c - \ell)_i$ is the rate of growth of the capital-labor ratio.

The effect of R&D is measured by γ; estimation in this context requires data on the growth of the stock of R&D capital. If, however, investments in R&D do not depreciate, then data on R&D intensity can be used to capture the R&D effect. If R_{it} is R&D expenditures in year t, then $k_t = R_{it}/K_{it}$, and $\gamma k_{it} = \rho(R_{it}/Q_{it})$, where ρ is the marginal product of R&D. Under competitive assumptions, ρ can also be interpreted as the rate of return.[5] Because employment and capital employed in R&D have not been segregated explicitly, this is an excess return to R&D expenditures. Further, it is a private return because the data pertain to individual businesses. Returns accruing to other firms and investors are not captured here.

Equation (3) provides a starting point for empirical analysis, but several adjustments seem warranted. In the first place, the model as specified ignores the

5. If R&D investments depreciate, as they most likely do, especially as far as private returns are concerned (see Pakes and Schankerman 1984) then the equation is misspecified by leaving out a term of the $-\delta K/Q$ form. Since K/Q and R/Q are likely to be positively correlated, this omission may bias the estimated R/Q coefficient downward, possibly by a rather large amount (since the R/Q coefficient in the K/Q auxiliary equation is likely to be significantly above unity).

role of intermediate products in production by implicitly assuming that materials (including purchases of intermediate products and energy) are proportional to output.[6] This problem can be dealt with by using information on purchases to expand the input list. It is, of course, possible to use data on materials to calculate a value-added version of output. But this too makes assumptions about the nature of the production process (e.g., materials are used in fixed proportion) which may not apply across all firms. While we have used materials in both ways, treating them explicitly as an input yields much better statistical results, and we shall focus on such results in the empirical work reported below. The variable we use is total purchases deflated by an index of materials prices.[7]

One of the reasons for adding materials as an input is our view that the technology of production is likely to vary across firms and industries. If that is true, estimation of (3) without adjustment could lead to misleading inferences about R&D. A first cut at this problem is to add a set of industry dummies so that parameter estimates are based on variation in productivity and its determinants within industries, with each industry having its own value of λ. Firm-specific variations in technology can be introduced by casting the estimation problem in a total factor productivity framework. Instead of estimating the output elasticities of capital and materials directly, we can use the observed factor shares for each business as an approximation (the two are identical in competitive equilibrium).

After rewriting the R&D variable in intensity form, adding materials and industry dummies and using factor shares, equation (3) becomes:

$$(4) \qquad f_i = \sum_{j=1}^{N} \lambda_j D_j + \rho(R_{it}/Q_{it}),$$

where j indexes industries, D is an industry dummy, and f_i is defined as:

$$(5) \qquad f_i \cong q_i - \alpha_i c_i - \delta_i m_i - (1 - \alpha_i - \delta_i)\ell_i .$$

The parameters α_i and δ_i are respectively the shares of capital and materials in the sales of the ith firm. To better approximate equilibrium values, we have averaged each firm's share over the sample period. Material's share can be calculated directly, since it is simply the value of purchases divided by sales. No data are provided on the wage bill, however, hence capital's share was estimated as depreciation plus profits divided by sales.[8] Profits are defined gross

6. As Griliches and Mairesse (1984) show, failure of the proportionality assumption may induce bias into the estimated R&D effects.

7. The data set contains no breakdown of purchases into energy and other intermediate inputs; use of aggregate purchases implicitly treats materials and energy as interchangeable.

8. The use of total profits in the calculation of the share of physical capital is likely to overstate capital's share, since some of the returns that accrue to R&D will be counted as return to capital. The error thus introduced may lead to a downward bias in the estimate of the rate of return to R&D. If total profits include returns to physical capital and the stock of R&D capital, so that

of R&D expenditures (we treat R&D as an investment), but net of marketing expenses.[9]

The specification of the basic productivity equation is based on what is essentially a long-term perspective. It is assumed that movements in total factor productivity reflect movements in the production frontier caused by R&D investment and disembodied technical change. In practice, businesses may deviate from the frontier, not only because of errors in optimization, but because of disequilibrium phenomena associated with fluctuations in demand and consequent changes in utilization.

One way to incorporate such factors into the model is to assume that the production function (and thus productivity growth) is composed of a long-term and a short-term component. R&D and disembodied technical change are assumed to affect only the long-term component in the manner specified in (4). The short-term component is specified to be a simple linear function of capacity utilization. Cast in growth rate form, these assumptions introduce the rate of change of capacity utilization as a variable in the analysis.

6.2.1 The Main Results

Estimates of several versions of the basic productivity model are presented in table 6.4. The dependent variable in columns (1)–(4) is the rate of growth of real sales per employee, while the growth of total factor productivity (TFP) is examined in columns (5) and (6). In addition to R&D intensity, the model includes variables measuring the R&D mix, the growth of capacity utilization, the newness of the capital stock, and the percent of employees unionized. Capital and materials per employee are included as independent variables in (1)–(4) and are incorporated into the dependent variable in the TFP regressions.

Irrespective of specification, the estimates in table 6.4 show a significant effect of R&D on the growth of productivity. In column (1), the model yields an estimated rate of return to R&D investment of 0.18 with a standard error of 0.05. The utilization rate as well as capital and materials per employee are significantly related to sales per employee. Correcting capital for inflation appears to have little effect on the estimated R&D effect. When the growth of gross book value per employee is substituted for $c - \ell$ in column (1), for example, the estimated return to R&D is still 0.18.

The newness variable has a negative sign, while unionization's impact is statistically insignificant. It is possible that the sign of the newness variable reflects measurement problems as well as the differential effects of newer capital. Although capital has been adjusted for inflation, the procedure relies on

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$\Pi = rC + \rho K$, then the estimated share of capital will be equal to the true share plus the elasticity of output with respect to R&D capital (note that $\rho K/Q = \gamma$). Use of the estimated share in a total factor productivity framework introduces $-\gamma_i c_i$ into the error term. If c and $RQ(-1)$ are positively correlated, estimates of ρ will be downward biased.

9. In those cases where profits in a given year were negative for a given firm, the average share for that firm was calculated excluding the negative year.

Table 6.4 **Estimates of Alternative Productivity Model Specifications (standard errors in parentheses)**

Independent Variables	Specification[a] Real Sales (1)	Real Sales (2)	Real Sales (3)	Real Sales (4)	TFP (5)	TFP (6)
CONS	0.49	2.13	0.88	2.34	1.08	2.53
	(0.51)	(1.32)	(0.52)	(1.35)	(0.52)	(1.35)
RQ(−1)	0.18	0.18	0.19	0.19	0.20	0.20
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
RMIX	−1.42	−1.22	−1.16	−1.11	−1.22	−1.15
	(0.59)	(0.61)	(0.60)	(0.62)	(0.60)	(0.62)
$c - l$	0.25	0.25	—	—	—	—
	(0.01)	(0.01)				
$m - l$	0.45	0.44	—	—	—	—
	(0.01)	(0.01)				
$(c - l)^{*}$[b]	—	—	1.17	1.17	—	—
			(0.06)	(0.06)		
$(m - l)^{*}$[b]	—	—	1.05	1.05	—	—
			(0.02)	(0.02)		
util	0.32	0.32	0.28	0.28	0.28	0.28
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
new	−0.05	−0.05	−0.04	−0.03	−0.03	−0.03
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
%UN	0.01	0.01	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Ind. effect[c]	no	yes	no	yes	no	yes
R^2	0.587	0.591	0.574	0.577	0.148	0.154
SEE	11.1	11.1	11.3	11.3	11.3	11.3
d.f.	4,138	4,119	4,138	4,119	4,140	4,121

[a]The dependent variable in columns (1)–(4) is real sales per employee; in columns (5)–(6) the dependent variable is TFP (total factor productivity), calculated as described in the text.

[b]$(c - l)^{*}$ is $(c - l)$ multiplied by capital's share; $(m - l)^{*}$ is $(m - l)$ multiplied by material's share.

[c]Industry effects are captured by two-digit SIC dummies.

estimates of replacement value in the first year of participation in the survey. To the extent that the correction fails to remove the effects of inflation, the rate of increase in the stock of capital will be overstated, a problem likely to be more serious for newer equipment. In fact, when column (1) is estimated with the book value of capital, the newness variable remains negative but increases by 30 percent. It is also possible that the negative sign remaining after the inflation correction is the result of adjustment costs of new capital. The integration of new equipment into existing plants or the start-up of new facilities may require time and effort to bring on line and may be disruptive to existing operations.

Measurement problems may also be a factor in the estimates of product-process mix effects. The coefficients on *RMIX* indicate that an increase in product R&D's share in total R&D investment is associated with a lower rate of productivity growth. High shares of product R&D may indicate a high rate of new product introduction which may be associated with lower rates of productivity growth for two reasons: First, much like new equipment, new products tend to be disruptive to established production processes. Product introductions generally involve a start-up and debugging phase of varying length in which new equipment or new tasks are specified and learned. Productivity growth is likely to suffer as a result. Second, where new products are an important aspect of competition, the business may adopt a relatively adaptable and flexible process technology. The firm is likely to avoid equipment and processes dedicated to a specific product and thus somewhat rigid. Some sacrifice in productivity is likely in the interests of flexibility. Although some of this should be picked up in the capital-labor ratio, this variable is likely to be too broad and rough to capture the distinctions we have in mind. It is well known, for example, that a highly capital-intensive machine shop can be quite flexible in adapting to new products. The R&D mix effect may, therefore, be an indication of the type of technology and the importance of new products.

While these possibilities are interesting, too much should not be made of the mix effect. The distinction between product and process R&D is likely to involve a good deal of arbitrariness. This arises because the guidelines are vague and because the distinction may not be meaningful at this level. Not only are process and product efforts jointly pursued on a project basis, and thus difficult to disentangle, but even pure product development can change the efficiency of the process. A new product design, for example, may lead to a reduction in the number of operations required or in a simplification of tasks, so that labor input is reduced even without any capital investment. Furthermore, if higher product R&D is associated with new products, and if firms base their price index on a fixed set of products, the reported rates of inflation may overstate the extent of price change. Output and productivity growth may, therefore, be understated. The fact that the standard errors on *RMIX* are relatively large, given the number of observations, lends some support to the importance of measurement error.

Finding a significant effect of R&D on productivity is unaffected by the specifications changes introduced in columns (2)–(6). Column (2) adds two-digit industry dummies, which allows each industry to have its own trend term. Estimation within industries has little effect on the results. In column (3), a new version of the capital and materials variables is used. The new variables are the rates of growth of capital and materials per employee multiplied by their average shares in sales. If the technology were Cobb-Douglas and the businesses were fully competitive, then coefficients on the new variables should equal unity. The materials and capital coefficients are significantly different from one in a statistical but not substantive sense, implying that the Cobb-Douglas specification is not too far off the mark. It is clear that the fit of the equation deteriorates only marginally when the average shares are imposed, and these changes, with or without industry effects, have little impact on the estimated return to R&D investment.

The same is true of the TFP equations in columns (5) and (6). We estimate that R&D had a return of 20 percent in the TFP results, slightly higher than the estimate in columns (1) and (2) but essentially similar to the earlier results. The other coefficients are little changed as well, although the newness variable declines from −.05 to −.03. As before, the industry dummies have no effect on the results.

6.2.2 Proprietary Knowledge, R&D Capability, and Technological Opportunity

Estimates of R&D's effect on productivity in table 6.4 are obtained under the assumption of a common effect across businesses. While differencing has eliminated fixed firm effects from the production function formulation, firms may also differ in their ability to translate R&D effort into actual products or processes. The productivity of R&D investment may depend on the "opportunity" for technical change in the firm's product or process. Some firms participate in industries where the scientific knowledge related to the product or process technology is rich and growing, while others use techniques where the possibility of new understanding is much more limited. Moreover, where the potential for innovation is high, firms may differ in their ability to exploit those opportunities because of differences in organization or management skill.

The likelihood of interfirm differences in technical opportunity and R&D capability suggests that the average effect of R&D in table 6.4 may mask significant variation across firms. A simple way to model the distinction between R&D effort (expenditures on R&D) and R&D output (new products or processes) and consequent gains in productivity is to assume that ρ is a function of the firm's R&D capability (or technical opportunity). If we assume that past R&D success is an indicator of that ability and if we are willing to specify a linear relationship between ρ and past success, we can write

$$\rho = b_0 + b_1 P, \tag{6}$$

where b_0 and b_1 are parameters, and P indicates previous R&D success (e.g., patents). It seems reasonable to allow for the possibility that past R&D success may affect productivity independent of the current R&D effort. The total factor productivity model then becomes

$$f_i = \lambda + b_0(R/Q)_{it} + b_1(R/Q)_{it}P_i + dP_i, \tag{7}$$

where the effects of utilization, unionization, newness, and industry have been suppressed.

Although we have no data on the number of patents the businesses have produced, we have three variables that provide some indication of R&D capability and technological opportunity. The first two are dummy variables based on answers to the question: Does this business derive significant benefit from (1) proprietary products and/or (2) proprietary processes? Patented products or processes are included in the definition, but firms are also instructed to consider processes (products) regarded as proprietary but not patented. The broader definition seems reasonable, since the decision to seek a patent depends not only on the significance of the invention or development and potential gains, but also on the costs of the legal process. Moreover, the firm may derive significant benefit from R&D results that are not clearly patentable.

The third variable is based on the question: Have there been major technological changes in the products or processes of this business or its major competitors within the last eight years? Inclusion of the firm and its competitors in the definition means that the variable provides information about the potential for change and development in the technology used in the industry, whether or not the firm itself has experienced a major change. The fact that a firm or its competitors have experienced a major change in technology can be interpreted in several ways. To the extent that an affirmative answer refers to the firm, one could infer that the firm has the capability to apply R&D and make use of the results. A similar conclusion would apply to competitors. However, the change in technology could have come through the purchase of equipment or licensing of new techniques rather than the firm's own R&D effort. Whatever the source of change, the fact that it has occurred implies the existence of further opportunities for technical development.

It is important to note, however, that asking a business about the occurrence of technical change may be equivalent to asking it about the productivity of its R&D investments. In that sense, inferences about the effects of technological opportunity based on the technical change variable may have little substantive content, since the estimated coefficient would be little more than a reflection of how accurately the businesses answered the question. While the possible tautology between our measure of technical opportunity and R&D productivity remains in the analysis to follow, it is mitigated to some extent by the fact that R&D investments are measured in the previous period, while changes in technology may have occurred sometime in the previous eight years.

It would clearly be useful to have more information about what firms have in mind when they answer yes to the technical change question. The PIMS guidelines warn respondents only to answer in the affirmative if there is no doubt that a major change has occurred. The meaning of the variable measuring technical change and proprietary products and processes deserves more analysis, but the nature of the data and the confidentiality provisions of the PIMS project make an in-depth analysis difficult and beyond the scope of this paper.[10]

Table 6.5 presents estimates of the TFP model after inclusion of our measures for R&D capability and technical opportunity. Although the results in line (1) with the proprietary product/process dummies show little change in the R&D effect, the new dummy variables are statistically and substantively significant. Furthermore, the sign pattern—negative on product, positive on process—is reminiscent of the R&D mix effect noted above. When the dummy variables are interacted with R&D intensity in line (2), however, we find little evidence of a significant relationship between R&D productivity and proprietary technology. Each of the interaction terms has the same sign as its dummy variable counterpart, but the coefficients are not statistically significant.

Lines (3) and (4) present TFP estimates with the technological change variable. While there appears to be no relationship between TFP growth and *DTECH,* there is a strong connection between *DTECH* and R&D intensity; the coefficient on *RQDTECH* is 0.24 and statistically significant. Moreover, the coefficient on $RQ(-1)$ in line (4) (which measures the R&D effect in businesses where $DTECH = 0$) is close to zero. If interpreted literally, the results imply that R&D has no effect on productivity in businesses where technical opportunities are apparently low. The connection between *DTECH* and R&D intensity links these finding with results reported by Griliches and Mairesse (1984), where R&D's largest effect on productivity was in R&D intensive firms. While interesting and worthy of further analysis, the statistical evidence in line (4) can be overinterpreted. It is useful to note that the addition of *DTECH* and its interaction with $RQ(-1)$ has little effect on the explanatory power of the equation.

10. While our ability to be precise about the substantive content of these variables is limited, we have examined them for internal consistency. A comparison of mean R&D intensity in samples selected on the basis of the presence or absence of technical change (*DTECH*) and proprietary technology (*DPROD, DPROC*) shows that firms with $DTECH = 1$ are almost twice as R&D intensive as their $DTECH = 0$ counterparts. A similar difference exists for firms where *DPROD* or *DPROC* equals one. We also found that 45 percent of firms with $DPROD = 1$ answer yes to the question about major technical change; for firms with $DPROD = 0$, the number is 23 percent. The results for *DPROC* are almost identical. This kind of consistency also shows up in analysis by industry. Not only are changes in technology correlated with proprietary products and processes within industries, but the industrial focus of major technical change is consistent with other information. The industries with high mean values of *DTECH*—paper, chemical, plastics, transportation equipment (including aerospace), instruments, and electrical equipment—are industries where major changes in technology have occurred.

Table 6.5 **The R&D Effect, R&D Capability, and Technological Opportunity[a] (standard errors in parentheses)**

Specification/ Dependent Variable	*CONS*	*RQ*(−1)	*DPROD*	*DPROC*	*DTECH*	*RQ DPROD*	*RQ DPROC*	*RQ DTECH*	R^2	*SEE*	d.f.
(1) *TFP*	0.26	0.19	−1.21	1.11	—	—	—	—	0.149	11.3	4,139
	(0.33)	(0.05)	(0.48)	(0.48)							
(2) *TFP*	0.38	0.13	−1.06	0.69	—	−.05	.15	—	0.149	11.3	4,137
	(0.36)	(0.07)	(0.56)	(0.55)		(.10)	(.10)				
(3) *TFP*	0.24	0.19	—	—	0.05	—	—	—	0.147	11.4	4,140
	(0.34)	(0.05)			(0.40)						
(4) *TFP*	0.58	0.02	—	—	−0.51	—	—	0.24	0.148	11.3	4,139
	(0.37)	(0.08)			(0.47)			(0.10)			

[a]Each equation includes *util, new,* and *%UN,* in addition to the variables listed.

6.2.3 Time Effects

Attention has been focused in recent years on possible changes in the productivity of R&D over time. Using aggregated industry data (two-digit SIC) from the 1970s, a number of researchers have documented the collapse of what had been a relatively strong R&D effect. Griliches (1979), Terleckyj (1980), Scherer (1981), and Kendrick and Grossman (1980) all find little evidence in two-digit level data that R&D affected productivity in the post-1973 period. Once the data are disaggregated, however, some R&D effect emerges. Griliches and Lichtenberg (1984), for example, find that the strong relationships found in the 1960s persisted into the later period.

Figure 6.1 presents a profile of the growth rates of TFP in the PIMS data and in published data on manufacturing. The published TFP estimates were prepared by Kendrick and Grossman (1980). Their output measure is based on real value added, and labor input is total hours worked. The TFP series from the PIMS data shows a downward trend over the 1970s, accompanied by sharp fluctuations associated with the business cycle. A similar pattern is apparent in the published data, although the timing and magnitude of cyclical swings in the 1974–76 period are somewhat different. These differences likely reflect differences in price indexes as noted earlier and differences in output and input definitions.

We examine the question of a decay in the potency of R&D in table 6.6, where estimates of the TFP model with a time trend and time-R&D interaction are presented. The specification also includes the variables measuring proprietary technology. Line (1) provides a base case, with the time trend entered separately without interaction with R&D intensity. It is evident that TFP growth slowed over the period covered by the data. The coefficient on *TIME*, negative and statistically significant, implies an average decline of .2 percent per year. The productivity of R&D, however, shows no tendency to decline. In line (2), the *TIME*-R&D interaction term is negative, but its standard error is quite large, and its actual value is quite small. The estimate of -0.171, for example, implies a decline of 1.7 percentage points in the rate of return over the decade of the 1970s. Evaluated at the midpoint of the time period, the implied rate of return in line (2) is 0.18, quite close to the estimate in line (1).

Lines (3) and (4) present estimates of the TFP model in the sample of firms where $DTECH = 0$ and in the sample where $DTECH = 1$. Looking first at line (3), there is some indication of a sizeable drop in R&D productivity, but the evidence is quite weak. The interaction term shows a decline of 4.8 percentage points per year in the return to R&D, but the standard error is relatively large. At the midpoint of the time period, the estimated return to R&D is -5 percent. When line (3) is reestimated without the time trend or the interaction term, the return to R&D is 1.3 percent with a standard error of 8.2.

In line (4) a very different picture emerges. As the estimates in table 6.5 indicated, R&D investment has a substantial impact on TFP growth in busi-

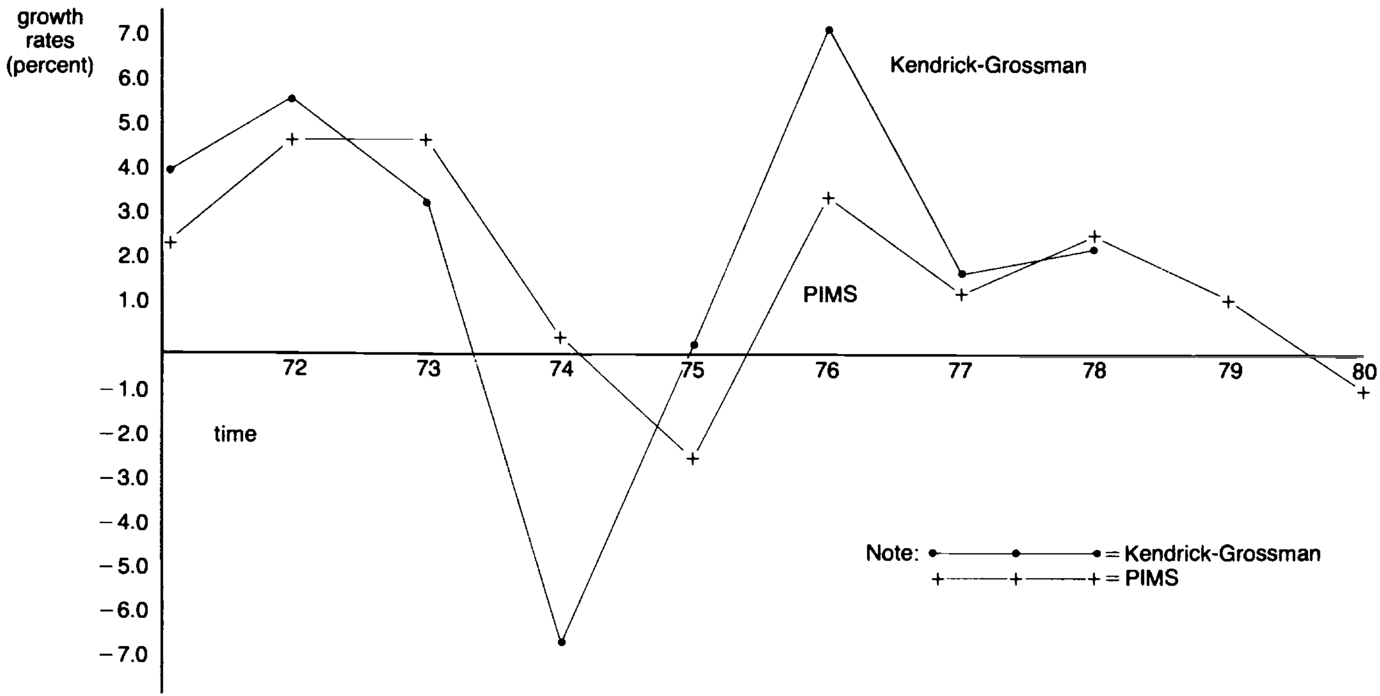

Fig. 6.1 Growth rates of total factor productivity in PIMS and Kendrick-Grossman, 1977–80

Table 6.6 **Trends in the Productivity of R&D (standard errors in parentheses)**

Specification[a] and Sample	*CONS*	*RQ*(−1)	*TIME*	*RQTIME* (× 10^2)	*DPROD*	*DPROC*	Rate of Return on R&D at Midpoint[b]	R^2	*SEE*	d.f.
Total Sample:										
(1) *TFP*	401.0	0.17	−0.20	—	−1.31	1.06	0.17	0.150	11.3	4,138
	(157.8)	(0.05)	(0.08)		(0.49)	(0.48)				
(2) *TFP*	393.3	3.56	−0.20	−0.171	−1.30	1.06	0.18	0.150	11.3	4,137
	(177.8)	(36.0)	(0.09)	(1.83)	(0.49)	(1.48)				
Tech Change Samples:[c]										
(3) *TFP;*	386.2	9.471	−0.20	−4.798	−0.54	0.52	−0.05	0.156	10.7	2,995
DTECH = 0	(220.6)	(76.03)	(0.11)	(3.85)	(0.59)	(0.59)				
(4) *TFP;*	79.9	−6.00	−0.04	0.317	−2.42	2.25	0.26	0.148	12.8	1,133
DTECH = 1	(380.2)	(46.79)	(0.19)	(2.37)	(0.91)	(0.91)				

[a]Lines (3) and (4) are based on observations for firms with *DTECH* = 0 and *DTECH* = 1, respectively.

[b]The midpoint of the time period was 1975; the rate of return in that year is equal to the coefficient on *RQ*(−1) plus the quantity 1975 times the coefficient on *RQTIME.*

[c]All equations include *new, util,* and *%UN.*

nesses where a major change in technology has occurred. In 1975, for example, the estimated return to R&D in line (4) is 26 percent. The interaction term implies a small increase of 0.3 percentage points per year in the return to R&D, but, once again, the standard error is enormous.

The evidence thus suggests that if one looks at businesses where technological opportunity apparently is high and where most of the R&D-productivity effect occurs, there is little statistical support for the notion that the return to R&D declined in the 1970s. In the rest of the sample, where the average return to R&D is very small, there is stronger support for a decline in R&D productivity, but the data do not provide us with a very precise estimate. Further analysis and data may help to clarify trends in the return to R&D in businesses where technological opportunity is low, but for now the evidence is inconclusive.

6.3 Conclusions and Implications

The estimates presented in tables 6.4–6.6 suggest that R&D investment has a significant positive effect on the growth rate of total factor productivity. All of the specifications examined yielded estimates of an 18–20 percent rate of return to R&D investment. We also found an important connection between the potency of R&D and technical opportunity. And while use of proprietary process technology appears to increase TFP growth, there is only weak statistical evidence of a relationship between the returns to R&D and the use of proprietary processes. Finally the notion that the potency of R&D declined in the 1970s finds little support in these data. Irrespective of model specification or sample used, the coefficient of the time and R&D intensity interaction is both small and statistically insignificant.

The fact that R&D investment continued to have a strong positive effect on productivity growth in the 1970s means that R&D may have played a role in the slowdown of productivity growth. From the early 1970s to the late 1970s, for example, the mean R&D-to-sales ratio fell from 2.7 to 1.9 percent in the PIMS data. With a rate of return to R&D of 20 percent, this would imply a decline of TFP growth of 0.16 percentage points, or about 10 percent of the decline observed over the period. We have found, however, that most of the effect of R&D comes in businesses where technological opportunity is high. Among those firms, a somewhat different perspective emerges. In that group, R&D intensity fell from 3.9 to 3.0 percent, while at the same time TFP growth fell from 4.1 to 3.0 percent. With a return to R&D of about 24 percent, the fall in R&D intensity could explain close to 20 percent of the decline in productivity growth in the high technical opportunity sector.

6.3.1 Further Work

Our analysis has uncovered some interesting relationships and left a number of issues open for further research. One of these issues is the mix between product and process R&D. Both the R&D mix variable and the variable indicating the use of proprietary products had negative effects on productivity growth. This suggests the possibility of some interesting connections between the product development process, choice of technology, and growth of productivity. Analysis of these questions in the PIMS data (and probably in other data sets as well) will have to confront serious measurement problems, especially difficulties in the measurement of prices and output.

There is also the possibility of improving the statistical methodology. All of the estimates presented here are based on ordinary least squares. Except for the use of growth rates, which sweeps out fixed effects, we have ignored the panel structure of the data. Using growth rates does eliminate an important source of autocorrelation, but other forms of covariation in the residuals of a given business may be present and could affect our estimates. If the sample were balanced, there would be little difficulty in applying some form of generalized least squares. An unbalanced design, however, calls for an approach accounting for the differences in numbers of observations within a business over time in calculating the relevant covariance matrix.

Finally, we have not examined explicitly the effect of R&D on costs, prices, and profits. It is well known that under competition the production function and TFP have a dual representation in the cost function as the difference between the sum of share-weighted input price growth rates and the growth of the output price. Although we have no data on the "price" of R&D, its effect in a price-side version of the TFP equation can be estimated using R&D intensity.

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