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9 R&D and Productivity Growth at the Industry Level: Is There Still a Relationship?

9.1 Introduction

A previous paper (Griliches 1980) explored the time-series relationship between total factor productivity (TFP) and cumulated past research and development (R&D) expenditures within different "2-1/2 digit" SIC level manufacturing industries. It used the Bureau of Labor Statistics' (BLS) Input-Output (I-O) sector level productivity and capital series and the National Science Foundation's (NSF) applied research and development series by product class as its data base and focused on the potential contribution of the slowdown in the growth of R&D expenditures to the explanation of the recent slowdown in productivity growth in manufacturing. Its main conclusions were: (1) The magnitude of the R&D slowdown together with the size of estimated elasticities of output with respect to R&D stock do not account for more than a small fraction of the observed decline in productivity. (2) When the data are disaggregated by period, almost no significant relationship was found between changes in R&D stock and productivity growth in the more recent 1969–77 period.[1] This led one commentator (Nordhaus 1980) to interpret these results as evidence for the hypothesis of the depletion of scientific opportunities. The paper itself was more agnostic, pointing to the large unexplained annual fluctuations in TFP and arguing that many of the recent observations were affected by unexpected price developments and large swings in capacity utilization and,

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[1] These findings were also consistent with the evidence assembled by Agnew and Wise (1978), Scherer (1981), and Terleckyj (1980).

hence, could not be interpreted as being on the production possibilities frontier and as providing evidence about changes in the rate of its outward shift.

A variety of problems were raised by the data and methodology used in that paper, some of which we hope to explore and to improve in this paper. There were, roughly speaking, three kinds of problems: (1) those associated with the choice of a particular R&D series; (2) those arising from the use of a particular TFP series; and (3) those associated with the modeling of the relationship between R&D and subsequent productivity growth. We shall address these topics in turn. To foreshadow our conclusions, we find that the relationship between an industry's R&D intensity and its productivity growth did not disappear. An overall decline in productivity growth has also affected the R&D intensive industries, but to a lesser extent. If anything, this relationship was stronger in recent years. What cannot be found in the data is strong evidence of the differential effects of the slowdown in R&D itself. The time series appear to be too noisy and the period too short to detect what the major consequences of the retardation in the growth of R&D expenditures may yet turn out to be.

9.2 The R&D Data

The major and only source of R&D data at the industrial level of detail are the surveys conducted by the Census Bureau for the National Science Foundation (see, e.g., National Science Foundation 1977). These surveys are based, however, on company reports and on the industrial designation of the company by its main line of activity. There are at least two problems with these data: (1) Many of the major R&D performers are conglomerates or reasonably widely diversified firms. Thus, the R&D reported by them is not necessarily "done" in the industry they are attributed to. (2) Many firms perform R&D directed at processes and products used in other industries. There is a significant difference between the industrial locus of a particular R&D activity, its "origin," and the ultimate place of use of the results of such activity, the locus of its productivity effects. In addition, one should also keep in mind the possibility of pure knowledge spillovers, the cross-fertilization of one industry's research program by developments occurring in other industries.[2]

There are various ways of dealing with such problems. We chose to use the NSF data on applied research and development expenditures by *product class* as the basis for our series.[3] The product-class classification is closer to the desired notion of R&D by industry of *use* and it is available at a reasonable level of SIC detail (twenty-eight distinct "2-1/2" digit groupings). It does attribute the fertilizer research of a "textile" firm to the fertilizer industry (but not

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2. Cf. Griliches (1979) for a more detailed discussion of these issues.

3. Other ways of dealing with this problem include the use of R&D by product class by industry of origin table (Schankerman 1979), input-output and capital flow of purchase table (Terleckyj 1974), and patents class by industry of origin and use table (Scherer 1981) to redistribute the NSF R&D data.

to agriculture) and the work on bulldozers of an "automotive" firm to the construction equipment industry (but not to construction itself). It is thus based on a notion of proximate rather than ultimate use. Nevertheless, it is much better conceptually than the straight NSF industrial origin classification scheme.[4]

Unfortunately, it is based on much more spotty reporting than the overall R&D numbers. Moreover, after using these numbers in the earlier study, we discovered rather arbitrary and abrupt jumps in the historical series as published by NSF. It appears that when the Census drew new samples in 1968 and 1977, it did not carry through the revisions of the published data consistently backward, leaving large incomparabilities in some of the years for some of the industries. We had to go back to the original annual NSF reports and splice together and interpolate between the unrevised and revised numbers to keep them somewhat comparable over time.[5]

The industrial classification of a particular R&D data set determines the possible level of detail of subsequent analysis. Since the two-digit industrial categories are rather broad, we would like to use finer detail where possible, for example we would like to separate drugs from chemicals or computers from all machinery. This, of course, influences our choice of total factor productivity series.

9.3 The TFP Data

Because we are interested in industrial detail below the usual two-digit level breakdown, we could not use some of the already published and carefully constructed total factor productivity series, such as Gollop and Jorgenson (1980) or Kendrick and Grossman (1980). In the previous paper we used the BLS growth study data based on the input-output classification of 145 sectors (95 of them in manufacturing; see U.S. Department of Labor 1979a) and associated physical capital data series. These data are subject to two major drawbacks: First, the output concept used by BLS is based on the product rather than the

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[4] NSF (1977, p. 70) instructs respondents to the industrial R&D survey to complete the "applied R&D by product field" item on the questionnaire as follows:

> Costs should be entered in the field or product group in which the research and development project was actually carried on regardless of the classification of the field of manufacturing in which the results are to be used. For example, research on an electrical component for a farm machine should be reported as research on electrical machinery. Also, research on refractory bricks to be used by the steel industry should be reported as research on stone, clay, glass, and concrete products rather than primary ferrous metals, whether performed in the steel industry or the stone, clay, glass, and concrete industry. Research and development work on an automotive head lamp would be classified in other electrical equipment and supplies, regardless of whether performed by an automotive or electrical company.

In fact, however, the majority of respondents interprets this question as relating to "industry of use" according to a recent internal audit by the Bureau of the Census.

[5] This work was done by Alan Siu and is described in more detail in appendix B.

establishment classification, which introduces an unknown amount of incomparability between the output measure and the associated labor and capital measures. The latter are based on the industrial classification of establishments rather than products. Second, the only available output concept is gross output (not value added), and there are no consistent official numbers on material or energy use below the two-digit industry level. The use of gross output and the lack of data on materials introduce a bias of an unknown magnitude that could be quite large during the seventies, when materials and energy prices rose sharply relative to the prices of other inputs.

Because of these problems, we turned to another source of data: the four-digit level, Annual Survey of Manufactures based series constructed by Fromm, Klein, Ripley, and Crawford (1979) as part of a joint Bureau of the Census, University of Pennsylvania, and SRI International (formerly Stanford Research Institute) project.[6] These data cover the years 1959–76 and contain information on material use by industry as well as separate information on energy use since 1971. Several problems also arise with this data set: First, it only goes through 1976. Second, the information on labor input available to us covered only production worker manhours, and we had to adjust it to reflect total employment. Third, the construction of these data is rather poorly documented, so one does not know how some of the numbers were derived or interpolated on the basis of the published sources. Nevertheless, they are very rich in detail and we hope to explore them further in subsequent work.

We used these data, after an adjustment of the labor input, to construct Tornqvist-Divisia indexes of total factor productivity at the relevant levels of aggregation (see appendix A for more detail). Table 9.1 presents estimated rates of growth of TFP between subperiod averages for manufacturing industries according to the breakdown given in the NSF R&D publications. In these data, a clear retardation in the rate of growth for most of the industries is evident already in the late sixties.[7]

Almost all TFP data start with some gross sales or revenues concept adjusted for inventory change and then deflated by some price index to yield a measure of "output in constant prices." Such a measure is no better than the price indexes used to create it. The price indexes are components of the Producer Price Index (PPI) and associated series reprocessed by the U.S. Department of Com-

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[6] We are indebted to David Crawford for making these series available to us.

[7] It should be pointed out that, because of the volatility of the annual TFP series, estimates of the timing and severity of the TFP slowdown (measured by the change in the average annual growth rate of TFP between two adjacent subperiods) are quite sensitive to the particular way in which the entire sample period is divided into subperiods. The weighted (by value of shipments) averages of the industries' beginning-, middle-, and end-of-period TFP average annual growth rates shown in table 9.1 are 1.72, 0.86, and 0.10, respectively. If instead of measuring changes between the mean level of TFP over several years, we compute average annual TFP changes between single "peak" years in business activity (as measured by the Federal Reserve Board index of capacity utilization for total manufacturing), the beginning, middle, and end subperiod definitions are 1959–65, 1965–73, and 1973–76, and the corresponding weighted TFP growth rates are 1.67, 1.23, and -1.94; almost all of the apparent slowdown occurs at the end of the period.

Table 9.1 **Average Annual Rates of Total Factor Productivity Growth between Subperiod Averages: Industries in NSF Applied R&D by Product Field Classification, in Percent[a]**

Industry	1959–63 to 1964–68	1964–68 to 1969–73	1969–73 to 1974–76
Ordnance	3.9	−0.9	1.4
Guided missiles	3.3	1.2	1.3
Food	0.7	1.2	−0.3
Textiles	1.5	1.6	−0.5
Plastics	2.8	2.6	0.3
Agricultural chemicals	1.6	2.3	1.2
Other chemicals	1.6	1.5	−1.3
Drugs	4.9	3.6	2.4
Petroleum refining	3.5	1.4	−9.8
Rubber	1.8	1.5	−1.1
Stone, clay, and glass	1.8	0.4	0.2
Ferrous metals	1.6	−0.4	−0.2
Nonferrous metals	0.6	−0.6	−0.3
Fabricated metals	1.9	0.4	−0.9
Engines and turbines	2.0	0.8	−0.9
Farm machinery	1.9	0.2	2.3
Construction machinery	2.2	0.1	−1.0
Metalworking machinery	1.7	−0.3	0.3
Computers	1.9	1.3	3.8
Other machinery	2.1	0.3	−0.3
Electrical transportation equipment	2.7	1.9	−0.3
Electrical industry apparatus	3.4	−0.2	0.0
Other electrical equipment	2.7	1.2	0.0
Communications equipment	2.3	2.0	1.6
Motor vehicles	1.7	0.8	−1.1
Other transportation equipment	2.8	0.5	0.3
Aircraft	3.4	0.4	2.1
Instruments	2.1	1.5	1.5

[a] Based on Tornqvist-Divisia indexes constructed from the Penn-SRI data base.

merce's Bureau of Economic Analysis (BEA) to yield a set of deflators used in the detailed deflation of the GNP accounts. As is well known, the quality of these deflators is quite variable.[8] Moreover, there is some reason to suspect that it may deteriorate further in periods of rapid price change, such as 1974–75, where there may be a widening of the gap between quoted prices and the average realized prices by sellers, many of whose prices may have been actually set earlier or not changed as fast as some of the more standard and widely traded and hence also collected items.

We tried rather hard to pinpoint such a deterioration in the price data and to find ways of adjusting for it, but without much success. Looking at the detailed

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[8] E.g., consider the obvious ridiculously low estimate of TFP growth for the computer industry in table 9.1. It is caused by the absence of a decent price index.

Table 9.2 **Correlation Coefficients between Rates of Growth or Rates of Acceleration of Prices and of Total Factor Productivity in Four-Digit Industries within Two-Digit Industries 35, 36, and 37**

	SIC 35 Machinery except Electrical	SIC 36 Electrical and Communication Equipment	SIC 37 Transportation Equipment
Rates of growth by period:			
1959–65	−.505	−.701	−.212
1965–73	−.717	−.816	−.252
1973–76	−.821	−.747	−.633
Rates of acceleration, period to period:			
1959–65 to 1965–73	−.521	−.532	−.217
1965–73 to 1973–76	−.782	−.519	−.622
Number of four-digit industries	44	39	17

data (either the BLS I-O sectors set or the Penn-SRI one), it becomes quite clear that many of the large TFP declines that occurred in 1974 and 1975 are associated with above average increases in the output price indexes used to deflate the corresponding industry revenue data. Table 9.2 illustrates the negative relation between TFP and output price growth for selected industries (based on four-digit detail) and its growth over time. Some of the reported price movements are large and bizarre and raise the suspicion that they may be erroneous. But without some alternative direct price or output measurement, it is difficult to go beyond such suspicions since, given the accounting identities and the assumption of competitive behavior, declines in productivity would produce a rise in the associated output price indexes.[9] We can either not believe in the reality of some of the reported productivity declines, in which case we also cast doubt on the price indexes that "produced" such declines, or we can accept both of them as a fact. Both views are consistent with the data as we have them. It would take an independent source of price or output data to adjudicate between these two points of view.

Before we turn to the analysis of the relationship of TFP growth and R&D expenditures, which can be looked at only at the same level of industrial detail as is available for R&D data, we can use the available four-digit detail to look at a few additional aspects of these data. An analysis of variance of annual changes in TFP at the four-digit level during the 1959–73 period illustrates the rather high level of noise in these data. Even in this earlier, relatively calm period only 20 percent of the variance is common at the two-digit level. That

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[9] In fact, given these identities, if factor prices move similarly for different industries and if factor shares do not change much, the correlation between TFP changes and product price changes should be close to −1.

is, most of the variance in TFP changes as computed is within two-digit industries. Similarly, only 8 percent of the variance is accounted for by common movements over time. The vast majority of the computed TFP movements are not synchronized. If these numbers are to be interpreted on their face value, as reflecting changes in industrial efficiency, these changes are highly idiosyncratic. Alternatively, if one believed that substantive causal changes in technological levels occur together for subindustries within a two-digit classification and follow similar time patterns, then this lack of synchronization would indicate a rather high level of error in these data.

Another issue of potential interest is whether the observed retardation in TFP growth at the two-digit level is also apparent at the four-digit level and is not just an artifact of a faster growth of lower productivity industries. Computations for three two-digit industries (35, 36, and 37) presented in appendix C, table 9A.1 indicate that this is indeed the case. If one held the four-digit industrial mix constant at the beginning period levels, the recorded TFP growth would have been even lower. When one looks at the computed rates of retardation (in the second part of table 9A.1), the effects are reversed, but the differences are quite small. The observed retardation is not an artifact, a "mix" effect. It actually happened quite pervasively at the four-digit level of industrial detail.

9.4 Modeling the R&D to Productivity Relationship

Many of the theoretical issues that arise in the attempt to infer the contribution of R&D to productivity growth from usual types of data were discussed at some length in Griliches (1979) and will not be considered explicitly here. But we want to mention and try to deal with three specific topics: (1) TFP measures as indicators of growth in technological potential; (2) the lag structure of R&D effects; and (3) the functional form and the econometric model within which such effects are to be estimated.

We have already discussed briefly the possibility that the TFP measures as computed are subject both to significant measurement error (arising mainly from errors in the level and timing of the output price deflators) and to large, short-run, irrelevant fluctuations. Irrelevant in the sense that though they do indicate changes in the efficiency with which resources are used, these changes occur as the result of unanticipated fluctuations in demand and in relative prices, forcing firms to operate their plants and organizations in a suboptimal fashion (at least from the point of view of their original design). Whatever theory one has of such business cycle and capacity utilization fluctuations, observations that are not on the production possibilities frontier are unlikely to be informative about the factors that are intended to shift this frontier. By and large, R&D expenditures are spent on designing new products, which will provide more consumer or producer value per unit of resources used, or new processes, which would reduce the resource requirements of existing products.

TFP fluctuations obscure such effects because the observed efficiencies do not reflect the potential ones and because during business cycle downswings there is a significant slowdown in investment with an associated, slower than normal, introduction and diffusion of new products and processes.

Within the limits imposed by our data, we tried three different ways of coping with such problems. The first was to assume that "true" productivity can only improve (no forgetting) and hence allows the TFP series to only increase or stay constant, but not decline, by resetting every "lower" observation to the previously observed peak level. The second approach tried to rule out large downward shifts in TFP that appeared to be caused by large changes in the price deflator and seemed to be inconsistent with the observed variable input (labor and materials) data. For example, if sales went up by 10 percent, and variable inputs went up by 5 percent, while the output price index went up by 15 percent, we would assume that perhaps up to one-half of the price movement was in error. The actual formula used was more complicated than that (it is described in the notes to table 9.3). The gist of it is that in the four-digit industries whose output per unit of variable input declined by more than 3 percent, and whose output price increases exceeded their respective two-digit industry average price increases by more than 5 percent, output was redefined so as to make "variable input productivity" decline *exactly* 3 percent. This adjustment affected about 24 percent (119 out of 486) of our annual observations.

Because neither of these procedures had a noticeable effect on our final results, we ultimately turned to the third and simpler way of coping with some of these problems: averaging. We picked subperiods, averaged the total factor productivity within each of these subperiods, and then computed rates of growth between such subperiod averages. In particular, the growth rate of TFP at the beginning of the 1959–76 period was defined by the average annual change between the mean level of TFP during 1959–63 and its mean level during 1964–68; the growth rates at the middle and end of the period were defined in terms of the changes in the mean level of TFP from 1964–68 to 1969–73, and from 1969–73 to 1974–76, respectively. We hope, in this way, to mitigate, if not solve, some of the difficulties discussed above.

We have very little to contribute on the issue of R&D lag effects. In the earlier work, only some of which was reported in Griliches (1980), we experimented at length with various lag structures, but largely to no avail. The data did seem to prefer, weakly, the no depreciation to the any depreciation assumption, and there was also some evidence of the possibility of rather long lags. Unfortunately, given the shortness of the series and the overall level of noise in the data, we could not really distinguish between a small, slowly decaying effect of R&D long past and fixed industry differences in their average levels of TFP. Thus, in this paper, we do not focus on this issue, but we hope to come back to it some day with better methods and data.

The common approach to the estimation of such models is to use the generalized Cobb-Douglas function in which a term involving some measure of R&D "stock" is added on, paralleling the role of physical capital. There is a problem, however, in applying such a framework across industries, since it is unlikely that different industries have the same production function coefficients. The TFP approach goes some ways toward solving this problem, by assuming that conventional inputs are used at their competitive equilibrium levels and by using the observed factor shares as approximations to the relevant production function elasticities. This allows each industry to have its own (a priori imposed) labor, capital, and materials coefficients. One is left, then, only with the estimation of trend and R&D effects.

The usual procedure (e.g., Griliches 1980) still imposes a common trend rate and a common output-R&D elasticity on all the data. The common trend restriction can be lifted by shifting to an analysis of first differences—the acceleration (or deceleration) in TFP growth—at the cost of magnifying the role of errors and short-term fluctuations in both the dependent and independent variables. The assumption of a common elasticity of output with respect to R&D stock is bothersome when the relationship is estimated *across* industries with well-known and long-term differences in R&D intensity. Unless the difference between the observed R&D "shares" in sales and the estimated overall common R&D elasticity parameter is to be interpreted as reflecting exact differences between the level of social and private R&D returns (which is not very likely), the estimated model is not consistent with any reasonable optimal R&D choice behavior. An alternative approach, used earlier by Griliches (1973) and Terleckyj (1980), is to reparameterize the model in terms of a common *rate of return* (marginal product) of R&D across industries, rather than a common elasticity. Writing the contribution of the change in the stock of R&D to TFP growth as

$$\gamma \dot{K}/K = \frac{\partial Q}{\partial K}\frac{K}{Q}\frac{\dot{K}}{K} = \rho\frac{\dot{K}}{Q} = \rho\frac{R - \delta K}{Q} \simeq \rho\frac{R}{Q},$$

where γ is the elasticity of output (Q) with respect to changes in the stock of R&D capital (K); $\rho = \partial Q/\partial K$ is the rate of return or marginal product of R&D; R is investment in R&D; and δ is the average rate of depreciation of R&D capital, the TFP growth rate can be expressed as a function of the R&D *intensity* of an industry, provided that δ is zero or close to it. This is the form that we will use in much of what follows.

9.5 Models and Main Results

We postulate a Cobb-Douglas production function (which may be viewed as a local, first-order logarithmic approximation to any arbitrary production function) which includes the stock of R&D capital as a distinct factor of production:

$$Q(t) = A \cdot K(t)^{\gamma} \cdot \prod_{i=1}^{4} X_i(t)^{\alpha^i} \cdot \exp(\beta t), \tag{1}$$

where $Q(t)$ = output; A = a constant; $K(t)$ = stock of R&D capital; $X_1(t)$ = labor input; $X_2(t)$ = stock of physical capital (structures and equipment); $X_3(t)$ = energy input; and $X_4(t)$ = nonenergy intermediate materials input. Define a conventional index of total factor productivity, $T(t)$, as

$$T(t) = Q(t) \Big/ \prod_{i=1}^{4} X_i(t)^{\alpha^i}, \tag{2}$$

normalized to 1 in 1972. By the first-order conditions for producer equilibrium, α_i—the elasticity of output with respect to the ith input ($i = 1, \ldots, 4$)—is equal to the share of the ith factor in total cost of production. Under the maintained hypothesis of constant returns to scale, $\Sigma\alpha_i = 1$.[10]

Combining (1) and (2),

$$T(t) = A \cdot K(t)^{\gamma} \cdot \exp(\beta t), \tag{3}$$

$$\log T(t) = \log A + \gamma \log K(t) + \beta t. \tag{4}$$

Differentiating (4) with respect to time and writing, for example, $[d\log T(t)]/dt = \dot{T}/T$,

$$\frac{\dot{T}}{T} = \gamma \frac{\dot{K}}{K} + \beta. \tag{5}$$

It is apparent from (1) that γ is the elasticity of output with respect to the stock of R&D capital, that is,

$$\gamma = \frac{\partial \ln Q}{\partial \ln K} = \frac{\partial Q}{\partial K} \cdot \frac{K}{Q}.$$

Hence, one may rewrite (5) as

$$\frac{\dot{T}}{T} = \frac{\partial Q}{\partial K} \cdot \frac{K}{Q} \cdot \frac{\dot{K}}{K} + \beta = \rho \frac{\dot{K}}{Q} + \beta, \tag{6}$$

where $\rho = \partial Q/\partial K$.

We estimated each of the three equations (4), (5), and (6) to measure the contribution of research and development expenditures to productivity. Although the deterministic versions of (4) and (5) are equivalent, they are not stochastically equivalent: in general, OLS estimation of (4) and (5) would yield different estimates of the parameter γ. In (4) and (5), the output elasticity of

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[10] There is a question about whether the coefficient of the R&D-stock variable should be included in the definition of constant returns to scale or not. Since the actual inputs purchased by the R&D expenditures are not segregated out of the conventional measures of labor and capital input, we avoid double counting by not including R&D in $\Sigma\alpha_i = 1$ and by interpreting its coefficient as representing both social and excess returns to this activity. See also note 13.

R&D capital is viewed as a parameter, that is, invariant across observations; in (6) the marginal productivity of R&D capital is a parameter. We argue below that ρ may be loosely interpreted as the social gross excess rate of return to investment in R&D. While there is no reason to expect the *social* rate of return to be equalized across industries, under the hypothesis that the discrepancy between social and private returns is distributed randomly across industries (or is at least uncorrelated with R&D intensity), an estimate of ρ obtained from (6) will be a consistent estimate of the *average* excess of social over private returns.

A variant of equation (4) was estimated on pooled time-series data (1959–76) for twenty-seven industries. Two modifications were made. First, each industry was specified to have its own intercept term, $\log A$. Rather than including twenty-seven industry dummies in the estimating equation, $\log T(t)$ and $\log K(t)$ were measured as deviations from the respective industry means. Second, the time trend was generalized to a set of time dummies. These time dummies control for all "year effects" common to the included industries. The actual specification of the estimating equation is therefore

$$(4') \qquad \log \tilde{T}(t) = \gamma \log \tilde{K}(t) + \sum_{\tau=1}^{T} \beta_\tau D_\tau ,$$

where a tilde above a variable denotes the deviation of that variable from its industry mean, and $D_\tau (\tau = 1, \ldots, T)$ is a set of time dummies.

It is well known that much of the year-to-year variation in total factor productivity is attributable to fluctuations in the level of capacity utilization. It is perhaps useful to view the TFP time series as the sum of a long-run trend and a serially correlated deviation from trend. We postulate that the level of the R&D stock is a determinant of the trend component of TFP, but not of its short-run deviations from trend; the latter are primarily the result of fluctuations in capacity utilization. A complete model of TFP should include variables accounting for both forces. Alternatively, if one is interested only in explaining the long-run behavior of TFP, one can attempt to remove some of the short-run variation from the observed series. We have tried both strategies in estimating equation (4′). In several equations we included a variable, average annual hours of work, postulated to be an indicator of the level of capacity utilization. In other equations we attempted to adjust TFP to its full-capacity level or to eliminate observations in which TFP was below capacity.

Table 9.3 presents regression results for variants of the model (4′). Line (1) includes no variable other than R&D stock and year dummies. Line (2) includes a measure of the age of the industry's plant ([gross plant − net plant]/gross plant), while line (3) also includes a utilization index, average annual hours of work per employee. In line (4), the dependent variable was defined as the minimum of the current level of TFP and the previous peak level of TFP. Observations in which TFP was below its previous peak were excluded in estimating the equation in line (5). The dependent variable in line (6) is "adjusted"

Table 9.3 **Summary of "Within" Industries' Total Factor Productivity Level on R&D Stock Regression Results: 27 Industries, 1959–76**

Dependent Variable	Coefficient (t-stat) on R&D Stock ($\delta = 0$)	Other Variables	R^2	Line Number
1	−.0014 (0.10)		.6317	(1)
1	−.0031 (0.22)	age	.6375	(2)
1	−.0048 (0.34)	age, hours	.6379	(3)
2	−.0387 (2.85)	age, hours	.7125	(4)
3	−.0014 (0.72)	age, hours	.7475	(5)
4	−.0012 (0.08)	age	.6589	(6)

Key to Dependent Variable (all variables defined as deviations from industry means):

1: Unadjusted TFP.

2: MIN (TFP, past peak TFP).

3: Excludes observations in which TFP < past peak TFP.

4: "Adjusted" TFP, based on the following rule for adjusting data at the four-digit level: If "variable input productivity" (output per unit of weighted index of labor, energy, and materials) declined by more than 3 percent, *and* the increase in the price of output exceeded the respective two-digit industry average price increase by more than 5 percent, redefine output so that variable input productivity declines exactly 3 percent.

TFP; the adjustment formula is described in the notes below the table. The coefficient on the R&D variable is negative in all cases and insignificantly different from zero in all but one case.

Before turning to a discussion of the results of estimating variants of the constant marginal productivity (or R&D intensity) model (6), we present in table 9.4 descriptive statistics on TFP and private R&D intensity (or R&D per unit of output) by subperiod for the twenty-seven industry sample.[11] Table 9.4 indicates that both the (unweighted) mean growth of TFP and the (unweighted) level of R&D declined throughout the period, and that the larger absolute decline in both variables occurred early. There is also a striking increase in the variability of TFP growth over time; the standard deviation rises by over 40 percent.

Plots of TFP growth against private R&D intensity by subperiod are shown in appendix C, figures 9A.1, 9A.2, and 9A.3. Note that the computer industry

[11] We dropped petroleum refining (SIC 29) from our sample because of clearly erroneous TFP numbers for recent years. The unadjusted numbers show TFP declining at the rate of 10 percent per year during 1973–76, mainly because the material price deflators are for some reason not rising as fast as the output deflators.

Table 9.4 Descriptive Statistics: TFP Growth and Privately Financed R&D Investment per Unit of Output, by Subperiod, 1959–76

	Mean	Std. Dev.	Minimum	Maximum
Average annual percent change in TFP, between periods:				
1959–63 and 1964–68	2.25	0.93	0.64	4.85
1964–68 and 1969–73	0.92	1.05	−0.92	3.60
1969–73 and 1974–76	0.39	1.29	−1.33	3.77
Privately financed R&D investment as percentage of output, average during period:				
1959–63	3.53	4.10	0.10	14.70
1964–68	3.01	3.13	0.20	11.46
1969–73	2.71	2.50	0.20	10.54

Correlation coefficients:	(1)	(2)	(3)	(4)	(5)	(6)
(1) TFP growth, 1959–63 to 1964–68	1.00	—	—	—	—	—
(2) TFP growth, 1964–68 to 1969–73	0.23	1.00	—	—	—	—
(3) TFP growth, 1969–73 to 1974–76	0.42	0.22	1.00	—	—	—
(4) R&D intensity, 1959–63	0.35	0.51	0.62	1.00	—	—
(5) R&D intensity, 1964–68	0.39	0.59	0.65	0.97	1.00	—
(6) R&D intensity, 1969–73	0.41	0.54	0.69	0.92	0.97	1.00

(*R*) is a consistent outlier in these charts. This is an industry whose productivity is clearly underestimated by the conventional measures.

At the bottom of table 9.4 we show correlation coefficients between TFP growth rates and R&D intensities. Note the extremely high, positive correlations between period-specific R&D intensities, indicating the stability of the industries' relative positions with respect to R&D performance. An alternative (nonparametric) way of analyzing the relationships between TFP growth and R&D intensity is to classify industries into groups, according to their rank in the R&D intensity distribution, and to compute the mean rate of TFP growth for each group. Mean TFP growth rates between adjacent subperiods by quartile of the R&D intensity distribution of the earlier period are reported in table 9.5. Industries were ranked according to both private R&D intensity and total R&D intensity. With a single exception, average TFP growth of industries in higher quartiles of the R&D intensity distribution is higher than average TFP growth of industries in lower quartiles, and this relationship appears to grow stronger over time.

We now turn to a discussion of estimates of the TFP growth, R&D intensity model. This model was estimated separately by subperiod under alternative assumptions about the rate of depreciation of R&D capital.[12] For each subperiod and depreciation rate assumption, two variants of the model were estimated: one in which R&D intensity is divided into privately financed and

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[12] Note that the R&D intensity is as of the beginning of the period. That is, the $\bar{R}$ associated with TFP growth between 1969–73 and 1974–76 is computed as $(K_{73} - K_{69})/5$, where K is the R&D capital stock constructed on the basis of the various depreciation assumptions.

Table 9.5 **Mean Rate of Total Factor Productivity Growth of Industries, by Quartile of (Private or Total) R&D Intensity Distribution**

Period and Source of R&D Financing	Industries Excluded from NSF R&D Classification[a]	Quartile of R&D Intensity Distribution lowest 1	2	3	highest 4
1959–63 to 1964–68					
Private R&D	0.34	1.56	1.96	2.72	2.85
Total R&D		1.56	1.96	2.64	2.94
1964–68 to 1969–73					
Private R&D	0.13	0.43	0.39	1.08	1.92
Total R&D		0.43	0.55	0.99	1.84
1969–73 to 1974–76					
Private R&D	0.07	−0.24	−0.12	0.55	1.44
Total R&D		−0.15	−0.22	0.22	1.93

[a]These industries' investment in R&D is negligible.

government-financed components, and one in which only total R&D is included. The estimates, reported in table 9.6, indicate that substitution of the R&D measures classified by source of financing for the total R&D figure results uniformly in an improvement in the R^2; in the latter two periods this improvement is dramatic. This improvement arises from relaxing the a priori constraint that the coefficients on the two types of R&D be equal. Obviously, the unconstrained coefficients differ greatly in magnitude and even in sign in half of the regressions. Since we can reject the hypothesis of equality of coefficients for privately and government-financed R&D, we shall confine our attention to estimates with R&D disaggregated by source of financing.

The equation for each of the three TFP growth rates indicates that both the highest R^2 and the highest t-statistic on private R&D are obtained under the 0 percent depreciation rate assumption, and that both of these statistics decline monotonically as the assumed depreciation rises. In this sense, the data clearly favor the hypothesis of no depreciation of R&D capital in terms of its effects on physical productivity of resources at the industry level.[13]

Although the coefficient on private R&D is only marginally significant in the 1959–63 to 1964–68 equation, the corresponding coefficients in the two later equations are significantly different from zero at the 1 percent level. Both the coefficients and the associated t-statistics grow larger over the period. Recall that the coefficient on R&D intensity in the TFP growth equation may be interpreted loosely as the social gross excess rate of return to investment in R&D. It is a social rate of return because it is based on output in constant

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[13] Strictly speaking, the data favor the hypothesis of no depreciation, conditional on the maintained hypothesis of a constant geometric (declining balance) depreciation scheme. Earlier experimentation with other depreciation schemes and lag structures indicates that this conclusion is rather robust.

Table 9.6 **Estimates of the Relationship between Averaged Total Factor Productivity and R&D Intensity, under Alternative R&D Depreciation Assumptions, by Subperiod (N = 27)**

Period and Depreciation Rate	R^2	C	Total R&D	R^2	C	Private R&D	Federal R&D
1959–63 to 1964–68							
0%	.1461	2.06	2.69	.2138	1.89	9.15	1.51
		(10.7)	(2.07)		(8.4)	(1.96)	(1.00)
10%	.1088	2.11	3.84	.1516	1.98	12.90	2.20
		(10.9)	(1.75)		(9.0)	(1.52)	(0.83)
20%	.0906	2.13	4.88	.1261	2.03	17.07	2.76
		(11.1)	(1.58)		(9.3)	(1.34)	(0.73)
30%	.0793	2.15	5.86	.1109	2.05	21.46	3.23
		(11.3)	(1.47)		(9.5)	(1.24)	(0.66)
1964–68 to 1969–73							
0%	.0303	0.83	1.38	.3120	0.37	20.33	−1.35
		(3.7)	(0.88)		(1.5)	(3.28)	(0.84)
10%	.0295	0.84	3.00	.3044	0.41	42.84	−2.82
		(3.8)	(0.87)		(1.7)	(3.20)	(0.80)
20%	.0303	0.83	5.71	.2941	0.42	71.47	−4.50
		(3.7)	(0.88)		(1.8)	(3.15)	(0.68)
30%	.0325	0.82	10.40	.2785	0.41	102.01	−5.96
		(3.5)	(0.92)		(1.7)	(3.04)	(0.52)
1969–73 to 1974–76							
0%	.1538	0.11	5.19	.4574	−0.54	33.86	0.69
		(0.4)	(2.13)		(1.9)	(4.20)	(0.29)
10%	.1495	0.09	32.14	.2981	−0.18	74.63	−14.14
		(0.3)	(2.10)		(0.6)	(3.16)	(0.57)
20%	.0028	0.39	−2.13	.2196	−0.03	103.15	−22.47
		(1.5)	(0.27)		(0.1)	(2.49)	(2.10)
30%	.0110	0.38	−3.98	.1459	0.11	109.04	−22.18
		(1.5)	(0.53)		(0.4)	(1.86)	(1.88)

prices rather than profit calculations. It is gross because it also includes a possible allowance for depreciation. And it is excess because the conventional inputs of labor and capital already include most of the R&D expenditures once at "normal" factor prices.[14] The estimates imply an average 9.2 percent social excess rate of return to privately financed R&D investment undertaken during 1959–63, a 20.3 percent rate of return to 1964–68 R&D, and a 33.9 percent return to 1969–73 investments.

The coefficient on government-financed R&D is not significant in any of the three equations, and it has the wrong sign in the second one. In contrast to the private R&D coefficient, the government R&D coefficient is largest and most significant in the first period.

The regressions reported in table 9.6 are of the form

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[14] This is only approximately correct. See Schankerman (1981) for a more detailed discussion.

$$\log\left(\frac{Q(+1)}{Q}\right) - \log\left(\frac{\mathrm{IN}(+1)}{\mathrm{IN}}\right) = \alpha_0 + \alpha_1\frac{\mathrm{NRD}}{Q},$$

where Q = output; IN = index of total input; and NRD = net investment in R&D. Note the presence of Q on both sides of the equation. This suggests the possibility that the observed positive correlation between R&D intensity and TFP growth may be partly spurious, arising, for example, from errors in measuring current output. One way of eliminating this potential source of spurious correlation is to estimate the equation using the *lagged* value of R&D intensity. Estimates of equations in which the lagged value of R&D intensity *replaced* the current value, and equations in which *both* lagged and current values were included are presented in table 9.7. For convenience, the zero-depreciation equations for the three subperiods from table 9.6 are reproduced in table 9.7. In view of our earlier results, the assumption of no depreciation of R&D capital was maintained throughout.

Substituting the lagged (i.e., 1959–63) value of total R&D investment per unit of output for the current (i.e., 1964–68) value in the 1964–68 to 1969–73 TFP growth rate equation slightly increases the R^2; when both variables are included, the lagged value dominates, although both are insignificant. When R&D intensity is disaggregated by source of financing, the R^2 of the current value equation is higher than that of the lagged value equation, although private R&D is significant in both cases. When both current and lagged intensity are included, current intensity dominates.

The current value of R&D intensity dominates the lagged value in all of the 1969–73 to 1974–76 TFP growth rate equations, although the lagged values are also generally significant, indicating that while perhaps slightly biased upward, the results reported earlier (in table 9.6) are not entirely spurious.

Although one's impressions about the timing and severity of the slowdown in TFP growth are sensitive to the periodization scheme adopted, that is, the particular way in which the entire sample period is divided into subperiods, some experimentation with alternative schemes indicated that the TFP growth/R&D intensity estimation results reported in this paper are not substantially altered by changing the subperiod definitions. Indeed, the finding that the association between productivity growth and R&D activity became *increasingly strong* over the period is even more apparent in results not reported in the paper (i.e., those obtained using the "peak-to-peak" periodization scheme described in note 7) than it is in the evidence presented above.

To summarize the regression results reported above: variants of the constant elasticity version of the TFP/R&D model (equation [4′]) estimated on pooled "within" annual data yielded estimates of the coefficient on R&D that were negative and insignificantly different from zero, whereas the constant marginal productivity version of the model (equation [6]) estimated on a cross section of subperiod averages yielded estimates of the R&D coefficient that were generally positive and significant, at least for private R&D when R&D expenditure was disaggregated by source of financing. In principle, this marked difference

Table 9.7 **Total Factor Productivity Growth Related to "Current" and "Lagged" R&D Intensity**

R^2	C	Current Total R&D	Lagged Total R&D	Current Private R&D	Lagged Private R&D	Current Federal R&D	Lagged Federal R&D
A. 1959–63 to 1964–68							
.1461	2.06	2.69					
	(10.1)	(2.07)					
.2138	1.89			9.15		1.51	
	(8.4)			(1.96)		(1.00)	
B. 1964–68 to 1969–73							
.0303	0.83	1.38					
	(3.7)	(0.88)					
.0333	0.82		1.45				
	(3.5)		(0.93)				
.0341	0.81	−1.23	2.65				
	(3.3)	(0.14)	(0.31)				
.3633	0.33			20.33		−1.35	
	(1.4)			(3.28)		(0.84)	
.2756	0.47				13.85		−0.97
	(2.0)				(3.02)		(0.60)
.4283	0.28			49.99	−22.16	2.30	−4.30
	(1.1)			(1.66)	(0.94)	(0.13)	(0.24)
C. 1969–73 to 1974–76							
.1538	0.11	5.19					
	(0.4)	(2.13)					
.1215	0.17		3.41				
	(0.7)		(1.86)				
.2777	−0.19	45.11	−29.67				
	(0.7)	(2.28)	(2.03)				
.4854	−0.58			33.86		0.69	
	(2.1)			(4.20)		(0.29)	
.4173	−0.41				26.22		0.35
	(1.5)				(3.91)		(0.20)
.5263	−0.68			42.82	−7.19	33.89	−24.21
	(2.4)			(1.24)	(0.26)	(1.14)	(1.09)

in results could be an artifact of either (a) difference in functional form; (b) difference in time period of observation (annual vs. subperiod average); or (c) both differences. To determine what the source of the difference in results was, we estimated the constant elasticity version of the model on subperiod averages, that is, we estimated equations of the form

$$\log \frac{TFP}{TFP(-1)} = \beta_0 + \beta_1 \log \frac{K}{K(-1)},$$

where K = average net stock of R&D over the period. As before, the model was estimated under alternative assumptions about R&D capital depreciation. The R&D coefficients obtained from estimating these equations were never significantly different from zero and were negative in the first and third subperiods under all depreciation assumptions. We may conclude that the relatively good R&D intensity results (compared to the R&D stock results) are not due to the averaging of periods, but rather to the difference in functional form, that is, to the assumption of a constant marginal product rather than a constant elasticity across industries.

A different source of data allows us a more disaggregated glimpse at the same problem. Estimates of the fraction of all employees engaged in research and development by three-digit industry ($N = 139$) are available from the 1971 Survey of Occupational Employment and enable us to estimate the TFP growth/R&D intensity model on more detailed data.[15] Results based on these unpublished BLS data must be interpreted with caution, however, since their reliability is subject to question because of the underrepresentation of central office workers in the survey sample. To render the results of this analysis comparable to our earlier estimates, we multiplied the ratio of R&D employment to total employment by labor's share in total cost of production in 1971. Assuming real wages (adjusted for interindustry differences in labor quality) are equal across industries, the resulting figure is proportional to R&D employment expenditures per unit of output, a proxy for the desired measure—real net R&D investment per unit of output. Unfortunately, we have only a single cross section for the year 1971 and are therefore forced to assume stability with respect to relative R&D intensity (an assumption warranted by the evidence presented earlier).

Estimates of the TFP growth/R&D intensity equation based on the 139 industry sample for different periods of TFP growth are shown in table 9.8. The results indicate a positive and significant coefficient on R&D intensity in all subperiods. Given that the costs of R&D scientists account for about half of total R&D expenditures, the estimated R&D intensity coefficients should be divided by about half to make them roughly comparable to those reported in tables 9.6 and 9.7. The resulting numbers are significantly higher than those reported for total R&D there but lower than the comparable numbers for privately financed R&D alone. Since the employment numbers reflect both privately and federally financed R&D activities, this is approximately as it should be if the earlier results are attenuated because of aggregation. In any case, here too no evidence of a *decline* in the "potency" of R&D is found.

9.6 Tentative Conclusion

The relationship between the growth of total factor productivity and R&D did not disappear in recent years, though it was obscured by the overall decline in the average growth rate of TFP. While fine timing effects cannot be deduced

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[15] See Sveikauskas (1981) for details about these data. We are indebted to Leo Sveikauskas for making these data available to us.

Table 9.8 **Total Factor Productivity Growth Related to 1971 R&D Intensity, 139 Three-Digit Manufacturing Industries**[a]

	R^2	C	R&D Intensity
TFP growth, 1959–63 to 1964–68	.0323	1.572 (11.9)	48.361 (2.14)
TFP growth, 1964–68 to 1969–73	.0294	0.436 (3.4)	44.207 (2.04)
TFP growth, 1969–73 to 1974–76	.0672	−0.646 (3.2)	107.85 (3.14)

[a] R&D data derived from 1971 BLS Survey of Occupational Employment.

from the available data, when one does not impose a constant elasticity coefficient across different industries, there appears to be a rather strong relationship between the intensity of private (but not federal) R&D expenditures and subsequent growth in productivity.

Appendix A
Total Factor Productivity Data

The present investigation has the advantage of making use of consistent data on intermediate inputs as well as on gross output and primary inputs. The index of total factor productivity used in the empirical analysis is defined as the ratio of real gross output (shipments adjusted for inventory change) to a Tornqvist index (a discrete approximation to the Divisia index) of four inputs: capital, labor, energy, and materials.[16]

The Tornqvist index of total input is constructed as follows:

$$\ln\left(\frac{I_t}{I_{t-1}}\right) = \sum_i [.5^*(S_{it} + S_{i,t-1})] \ln\left(\frac{X_{it}}{X_{i,t-1}}\right),$$

where I_t = index of total input; S_{it} = share of factor i in total cost, $i = K, L, E, M$; X_{it} = quantity of factor i, $i = K, L, E, M$. This formula generates a sequence of growth rates of aggregate input; the *level* of the index in any given year is determined by an arbitrary normalization. The level of total factor productivity

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[16] Because expenditure on energy was included in materials expenditure in most years prior to 1971, the input index for the years 1959–71 is based on only three inputs: capital, labor, and the energy-materials aggregate. The input index for 1971–76 (the period during which the relative price of energy increased dramatically) treats energy and materials separately. Construction of the input index for the whole period consisted of defining a three-input index for 1959–71; defining a four-input index for 1971–76; normalizing both indexes to unity in 1971; and splicing the two indexes together in that year.

is defined as the ratio of output to aggregate input; the latter is normalized so that TFP equals unity in 1972.

The data base was developed jointly by the University of Pennsylvania, the U.S. Bureau of the Census, and SRI International as part of a project under the direction of Gary Fromm, Lawrence Klein, and Frank Ripley. It consists of annual time series (1959–76) on the value of output (shipments adjusted for inventory change), capital, labor, energy, and materials, in current and constant (1972) dollars, for 450 SIC four-digit industries in U.S. manufacturing. The source for most of these series is the Annual Survey and Census of Manufactures. Data for years prior to 1972 were reclassified to conform to the 1972 SIC scheme so that the industry classification is consistent throughout the period.

The following is a brief summary of salient characteristics of the data underlying the total factor productivity indexes. For a more detailed discussion of data sources and methodology, see the appendix to Fromm et al. (1979).

Output. Current dollar output is defined as value of industry shipments adjusted for changes in finished goods and work-in-process inventories. Constant dollar output is derived by deflating the current dollar series by deflators developed by the Industry Division of the Bureau of Economic Analysis. These deflators are constructed at the five-digit level and are generally weighted averages of BLS producer price indexes.

Capital. Consistent with the maintained hypothesis of constant returns to scale, the current dollar value of capital services is computed as the difference between the value of output and the sum of expenditures on labor, energy, and materials.[17] The real flow of capital services is assumed to be proportional to the real capital stock; the capital stock concept is the gross fixed reproducible stock of capital, that is, the stock of plant and equipment net of discards (land and working capital are excluded). The stocks are computed from a perpetual inventory algorithm, which takes account of the industry- and year-specific distribution of expenditures on investment goods across one plant and twenty-six equipment categories (based on a series of capital flow matrices extrapolated from a 1967 matrix by a biproportional matrix balancing procedure). This information on the composition of capital purchases enables development of industry- and year-specific weights for the construction of investment deflators and service lives (weighted averages, respectively, of the PPI's and the service life assumptions for the twenty-seven types of investments).

Labor. The current dollar value of labor services is measured as total expenditures by operating manufacturing establishments for employee compensation, including wages, salaries, and both legally required and voluntary supplements to wages and salaries. We adjusted for the compensation of employees in central administrative offices and auxiliaries. In the absence of data on hours of work of nonproduction workers, real labor input is defined as the ratio of

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[17] Because expenditures for business services such as advertising and legal services are not accounted for, the value of capital services and capital's share in total cost of production are probably slightly overstated.

total wages and salaries to average hourly earnings of production workers; under the assumption that the relative wages of production and nonproduction workers are equal to their relative marginal productivity, this ratio may be viewed as an index of "production worker equivalent" manhours. No adjustment was made for changes in labor quality from, for example, shifts in the age or sex distribution of employment.

Energy and other intermediate materials. Current dollar energy input is defined as the value of energy consumed in the production process; it includes energy produced and consumed within an establishment as well as purchases of energy from other establishments. Real energy input is obtained by deflating the current dollar series by a fixed-weighted index of three principal energy prices. Current dollar cost of materials is deflated by a fixed-weighted index of 450 four-digit manufacturing output price deflators and 7 one-digit nonmanufacturing price deflators. The weights for both energy and materials reflect the composition of the industry's purchases of intermediate inputs, as shown in the 1967 input-output table.

Appendix B

Smoothing the Applied R&D Series[18]

1972–75 Data Revision

The 1972–75 data were revised in 1976 because a new sample was drawn in 1976 and a response analysis study was conducted in 1975 which helped to improve respondents' interpretation of definitions of the survey. Consequently, the 1976 data may not be directly comparable to earlier ones. Among the twenty-seven product fields (excluding ordnance, guided missiles, and spacecraft) were three kinds of revision:

Revisions	*No. of Product Fields*
1. 1972–74 figures increased, 1975 figure decreased	17
2. 1972–74 figures unchanged, 1975 figure decreased	7
3. 1972–75 figures increased	3

Obviously, the first and second revisions result in sharp deceleration of the growth rates between 1974 and 1975, relative to the original series. The rationale behind this pattern of adjustment is unknown. As an alternative, the 1971–75 original annual growth rates were scaled by the 1975 adjustment factor,[19] thereby preserving the 1971–75 overall growth rates in smoothed series.

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[18] Prepared by Alan Siu.

[19] Log (1975 revised/1975 original).

Stone, Clay, and Glass Products

The data for 1968–70 are given as 130, 157, and 128. The 1970 figure was originally reported as 159 and then revised to 128 in 1971, resulting in a big spike in 1969. The 1969 figure was set as 126 (157 × 128/159).

Fabricated Metal Products

Between 1967 and 1968 there is a 134 percent jump in the data. This break is the result of an abrupt increase of applied R&D done by the electrical equipment and communication industry in the fabricated metal product field, from $49 million to $224 million. To smooth out the series, the 1962–68 growth rate was used as a control total to adjust the annual growth rates within this period.

Electrical Equipment

The data for this product field are not broken down into four subfields between 1967 and 1970. The average shares in 1966–67 and 1971–72 were used to disaggregate the total figures.[20]

Appendix C

Table 9A.1 **Weighted Averages of Four-Digit Rates of Total Factor Productivity Growth and Acceleration, 1959–76, by Selected Two-Digit Industries**

	SIC 35	SIC 36	SIC 37
A. Weighted average of four-digit rate of TFP growth:			
1959 value of shipment weights	0.379	1.558	0.910
1976 value of shipment weights	0.421	1.821	0.925
Correlation coefficient between rate of TFP growth and change in share of two-digit industry value of shipments, 1959–76	.164	.304	.505
B. Weighted rates of acceleration of TFP between 1959–63 to 1964–68 and 1964–68 to 1969–73:			
1959 weights	.077	−1.81	−1.29
1967 weights	.022	−1.82	−1.31
C. Weighted rates of acceleration of TFP between 1964–68 to 1969–73 and 1969–73 to 1974–76:			
1967 weights	−3.52	−2.09	−2.35
1976 weights	−3.62	−2.39	−2.79
Number of industries	44	39	17

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[20] The 1967 data are available separately for the four subfields.

Table 9A.2 **Selected TFP and R&D Data, by Industry in NSF Product-Field Classification**

	TFP Growth			R&D Intensity			Federal Share in R&D	
SIC Code	1959–63 to 1964–68	1964–68 to 1969–73	1969–73 to 1974–76	1959–63	1964–68	1969–73	1973	1977
348	3.9	−0.9	1.4	10.6	5.3	5.6	74.8	80.2
376	3.3	1.2	1.3	66.1	69.1	50.6	89.7	90.0
20	0.7	1.2	−0.3	0.2	0.2	0.2	0	0
22	1.5	1.6	−0.5	0.1	0.2	0.3	0	0
282	2.8	2.6	0.3	12.8	9.5	5.7	1.6	2.1
287	1.6	2.3	1.2	1.8	3.0	3.1	1.1	0.8
281, 284–286, 289	1.6	1.5	−1.3	3.5	3.1	2.4	1.1	2.1
283	4.9	3.6	2.4	8.5	8.3	7.0	1.6	1.3
30	1.8	1.5	−1.1	1.2	1.2	1.2	34.3	34.3
32	1.8	0.4	0.2	0.6	0.7	0.7	7.5	7.5
331, 332, 339	1.6	−0.4	−0.2	0.4	0.4	0.4	3.8	1.7
333−336	0.6	−0.6	−0.3	0.6	0.5	0.5	3.8	1.9
34	1.9	0.4	−0.9	0.6	0.7	1.4	44.0	52.5
351	2.0	−0.8	−0.9	6.1	5.9	5.0	7.6	9.6
352	1.9	0.2	2.3	3.1	2.5	1.9	7.6	0
353	2.2	0.1	−1.0	1.2	1.3	1.9	7.6	0
354	1.7	−0.3	0.3	1.3	1.1	1.1	7.6	0
357	1.9	1.3	3.8	15.9	12.4	11.4	13.7	7.5
355, 356, 358, 359	2.1	0.3	−0.3	1.7	1.2	1.0	12.3	7.4
361	2.7	1.9	−0.3	4.3	4.0	5.1	21.4	43.1
362	3.4	−0.2	0.0	3.5	3.0	3.7	21.4	13.1
363, 364, 369	2.7	1.2	0.0	2.4	2.1	2.1	21.4	28.8
365–367	2.3	2.0	1.6	25.0	14.7	11.6	55.0	48.7
371	1.7	0.8	−1.1	2.2	1.8	2.3	3.5	3.5
373–375, 379	2.8	0.5	0.3	0.8	0.9	1.5	55.2	55.2
372	3.4	0.4	2.1	14.9	12.5	14.2	67.8	68.8
38	2.1	1.5	1.5	4.5	5.6	5.6	27.6	21.7

Key to Symbols Used to Represent Industries in Appendix C Figures 9A.1, 9A.2, and 9A.3

Symbol	Industry	SIC Code
A	Ordnance and accessories, N.E.C.	348
B	Guided missiles and spacecraft	376
C	Food and kindred products	20
D	Textile mill products	22
E	Plastics materials and synthetic resins, rubbers and fibers	282
F	Agricultural chemicals	287
G	Other chemicals	281, 284–286, 289
H	Drugs and medicines	283
I	Rubber and miscellaneous plastics products	30
J	Stone, clay, and glass products	32
K	Ferrous metals and products	333, 332, 339
L	Nonferrous metals and products	333–336
M	Fabricated metal products	34
N	Engines and turbines	351
O	Farm machinery and equipment	352
P	Construction, mining, and materials-handling machinery and equipment	353
Q	Metalworking machinery and equipment	354
R	Office, computing, and accounting machines	357
S	Other machinery, except electrical	355, 356, 358, 359
T	Electric transmission and distribution equipment	361
U	Electrical industrial apparatus	362
V	Other electrical equipment and supplies	363, 364, 369
W	Communication equipment and electronic components	365–367
X	Motor vehicles and equipment	371
Y	Other transportation equipment	373–375, 379
Z	Aircraft and parts	372
7	Instruments	38

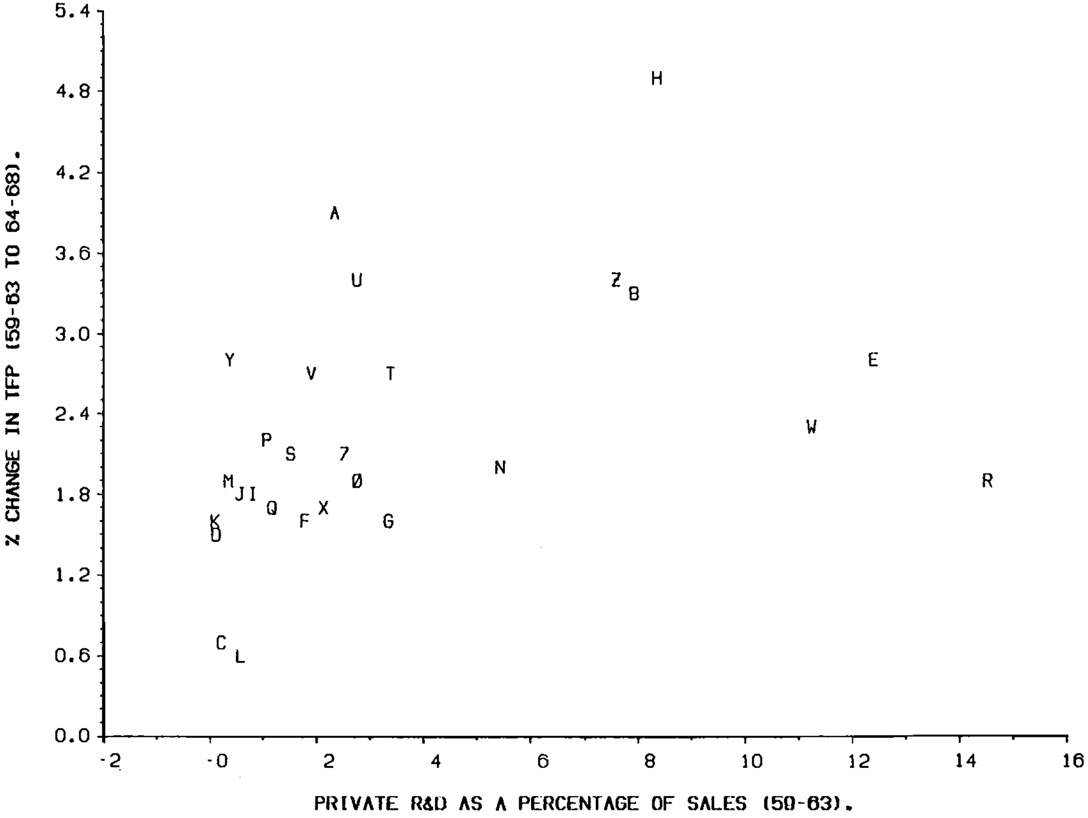

Fig. 9A.1 TFP growth versus private R&D intensity, 1959–63 to 1964–68

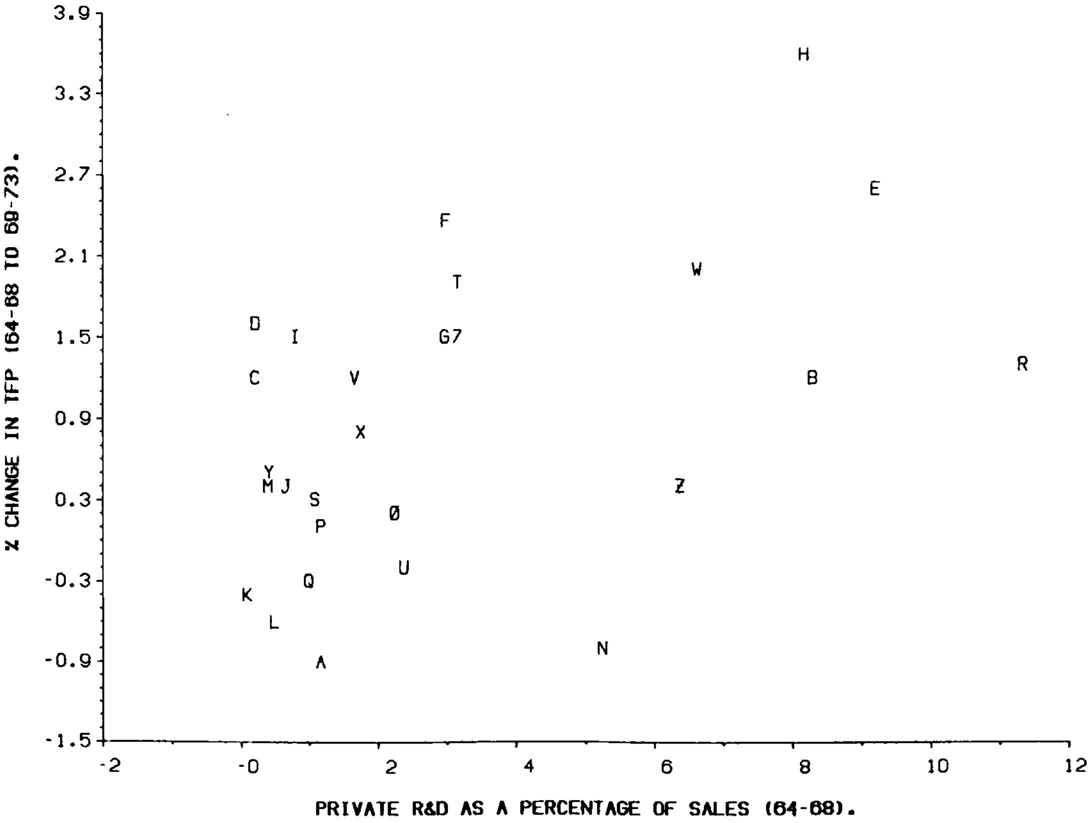

Fig. 9A.2 TFP growth versus private R&D intensity, 1964–68 to 1969–73

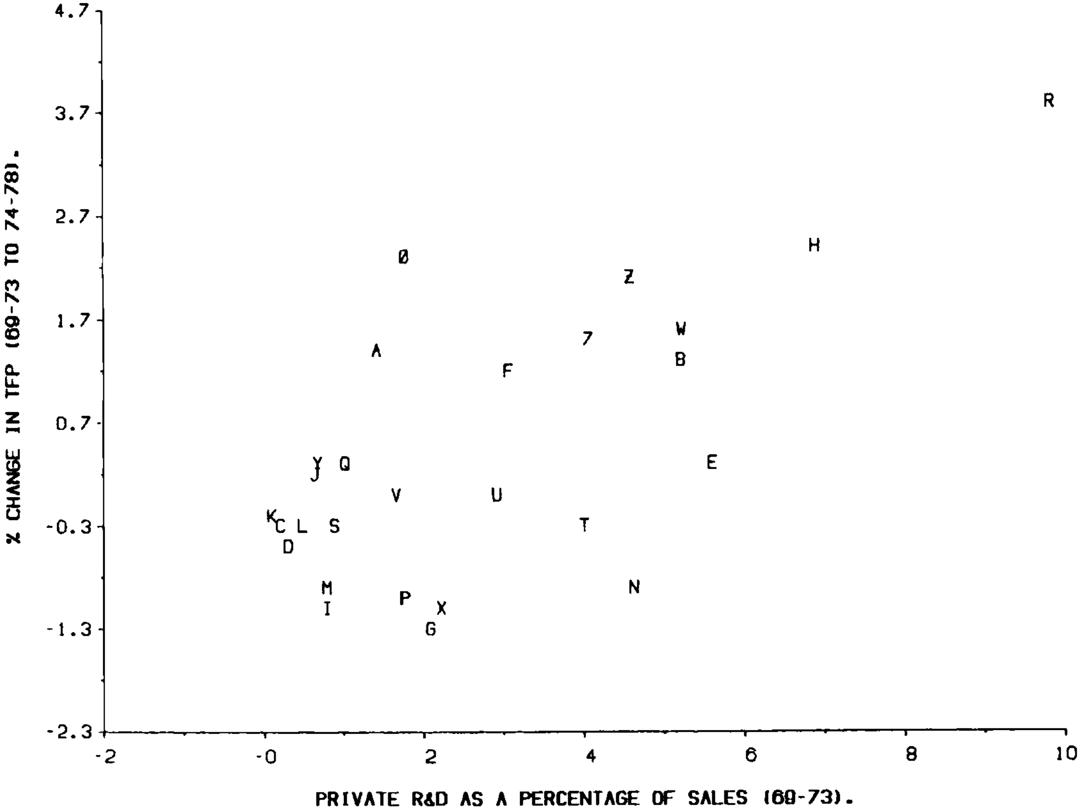

Fig. 9A.3 TFP growth versus private R&D intensity, 1969–73 to 1974–78

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