NBER WORKING PAPER SERIES

CONTRIBUTIONS AND DETERMINANTS OF RESEARCH AND DEVELOPMENT EXPENDITURES IN THE U.S. MANUFACTURING INDUSTRIES

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Working Paper No. 360

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge MA 02138

June 1979

The research reported here is part of the NBER's research program in Productivity. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

NBER Working Paper 360
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SUMMARY

This paper is an attempt to assess the contribution of R & D to growth of output in U.S. manufacturing industries. The important issues to address are: whether the slower growth of R & D expenditures in recent years has been the cause of slowdown in the growth of productivity, and what the factors are in explaining the slower growth of R & D expenditures. After a brief survey of the major issues on this topic, a production function is formulated and estimated using time series cross-section data for the manufacturing industries. Also, the factors determining the rate of growth of R & D expenditures in the 1958-75 period are identified by formulating a dynamic model of demand for R & D activity.

The estimation results indicate that the stock of R & D, as a measure of stock of knowledge, positively and strongly affect growth of output in total manufacturing, total durable, and total nondurable industries. Potential growth of output is affected because of the slowdown of growth of stock of R & D since 1966, but the gross rates of return on stock of R & D have not changed much in the 1966-75 period. Growth of output, changes in relative prices, cyclical fluctuations of the economy, as well as changes in level of employment and capital stocks are the factors affecting R & D expenditures. The effect of government financing of R & D on private decisions regarding R & D expenditures differs among different industries. By and large, the results on this issue are basically inconclusive and require further investigation.

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CONTRIBUTIONS AND DETERMINANTS OF RESEARCH AND DEVELOPMENT EXPENDITURES IN THE U. S. MANUFACTURING INDUSTRIES

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A large body of research has been devoted to discovering the sources of productivity growth in the United States. Aside from the contributions attributed to a growth in quantity and an improvement in quality of the factors of production, such as capital and labor, it is often argued that a major contributor to growth of output is technological change.[1] The rate of technical progress is determined by diverse factors and the underlying process that characterizes technical change is complex. However, research and development (R & D) is considered to be a major determinant of technical progress. The bulk of studies surveyed by Edwin Mansfield [24,1972] came to the conclusion that industrial research and development expenditures contributed significantly to growth of output and productivity resulting in positive and substantial private and social returns.

Since 1971 it has become increasingly apparent that productivity growth in the United States private sector has slowed down appreciably. Part of this slowdown is attributed to the substantial decline in the rate of growth of R & D expenditures. Consider the following statistics: from 1953 to 1961 R & D expenditures in real terms increased at an average of about 14 percent for government and 7.1 percent for non-government sponsors; from 1961 to 1967 these growth rates were decidedly lower--5.6 percent for government-funded and 7.4 percent for private R & D.

But from 1967 to 1975 the growth rate of government and private R & D expenditures dropped to 3 percent and 1.8 percent, respectively.

Given these figures, and the received conventional wisdom of high rates of return to R & D efforts, two questions arise:

(1) Have the contributions of R & D to growth of output and productivity remained as high in recent years as suggested in the literature?

(2) What factors account for the sharp decline in R & D expenditure since 1967?

To answer these questions it is necessary to review briefly what has been reported in the literature and to provide evidence to validate or contradict, wherever possible, some of the conclusions about the role and determinants of R & D. Specifically, we shall attempt to focus on three issues: first, to provide a summary of the findings of studies on the contribution of R & D expenditures; second, to provide some new estimates for the contribution of R & D to growth of output in total manufacturing, total durables and total nondurables industries; third, to assess the factors that determine the rate of growth of research and development.

In the first section, we shall briefly examine the findings of the studies reported in the literature since 1970 on the contribution of R & D to growth of output and productivity. A brief survey of the studies that attempts to explain the behavior of R & D expenditures will be presented in Section II. In the third section, we shall examine the results obtained from the econometric production function approach using a sample of pooled cross section-time series data for the period 1955-75 for the three industry sectors mentioned. The fourth section will pertain to the specification of a demand function for the stock of R & D in order to find out whether growth of output, changes in relative prices, and past stocks of other inputs affect the level and growth of the R & D input. Particular attention will be given to an examination of the effect of publicly funded R & D on private R & D expenditures. The conclusions and some suggestions for policy and future research are stated in Section V.

I. CONTRIBUTION OF R & D TO GROWTH OF PRODUCTIVITY: RECENT EVIDENCE

An ubiquitous finding of all empirical studies summarized several years ago by Mansfield [24,1972] was that R & D expenditures contribute substantially to the growth of output in a variety of industries. Subsequent studies have confirmed these findings but have gone beyond earlier studies in a number of ways. Their coverage is much broader, e.g., one study includes a sample of about one thousand U.S. industrial firms. More attention has been paid to inter-industry technology flows, and distinctions have been drawn between the returns from privately financed and federally financed R & D. The overall findings are that the rate of productivity of a firm or industry increases with an increase in its rate of expenditures on R & D and that the marginal rate of return from investment in R & D is very high. Confirmation of these conclusions becomes more striking when we note that some of the studies analyse individual R & D projects, others firm and industry data.[2/] We shall briefly describe some of the specific issues concerning the contributions of R & D to growth of output.

Direct Contributions

Several studies indicate positive but varying contributions of an increase in R & D expenditures to the rate of growth of output in different industries. Using seventeen two-digit industries, William Leonard [20,1971] analysed the relationship between growth of productivity and R & D intensity (defined by the ratio of company R & D to net sales or the number of company-financed R & D scientists and engineers per one thousand employees). He found that productivity growth can be explained by research intensity, total man-hours, and skill level of the employees (measured by median number of school years completed). His correlation analysis indicated that causality runs from R & D spending to industrial growth and not the reverse.3/ Nestor Terleckyj [38,1974], using a sample of 33 industries, correlated growth in total factor productivity for the period 1948-1966 with non R & D variables, such as percent of sales to the private sector, degree of union membership, annual rate of cyclical change in output, the ratio of investment in plant and equipment to value added and two types of R & D expenditure: privately financed and government financed. The results showed a strong direct effect of privately financed R & D on growth of factor productivity and no discernible effect by government-financed R & D. The explanation may be that government-financed R & D, unlike privately financed R & D, can be viewed as a distinct output of the performing industry rather than as an investment in its stock of knowledge. The contribution of firm-financed R & D to growth of productivity was calculated to be about 0.36 percent. Zvi Griliches [10,1973], using Census data for 883 large R & D-performing companies, reported that the contribution of R & D to growth of productivity differed considerably among industries as did the estimated output elasticities and derived rates of return for R & D. The main source of productivity differences was the differences in ratio of output to R & D capital stock among the industries. His results indicated that growth of productivity, besides depending on growth of R & D, was affected significantly by growth of plant and equipment of different industries.

Effects of R & D Embodied in Purchased Goods

Measured productivity in a given industry can increase through the purchase of R & D-intensive capital or intermediate goods from other industries. For example, R & D-intensive capital goods such as computers may result in a productivity increase in banking and insurance industries which do not undertake any significant R & D of their own. Research-intensive intermediate goods, such as fertilizers and agriculture and pre-fabricated structures in the construction industry, contribute greatly to the productivity measured in the industries using them. These indirect spillover effects of industry R & D have not received the attention they deserve nor is the underlying dynamic process of the transmission of technical change via the industrial input-output structure well understood.

There are a few studies, however, that have begun exploration of these issues. Terleckyj [38,1974] has estimated the contribution of R & D embodied in purchased goods for 33 manufacturing and non-manufacturing industries for the period 1948-66. The results indicate a strong effect by R & D intensive purchased inputs on productivity growth; rates of return of 45 percent in manufacturing, 62 percent for total industries, and 187 percent for non-manufacturing are attributed to the indirect effect of R & D through purchased inputs. Terleckyj sets the estimated indirect effect of private R & D at 80 percent, more than twice the direct rate of return of 30 percent. These results are in contrast to the estimates obtained by Griliches, which are 20 percent each for direct and indirect R & D, and to rate of return obtained by Mansfield et al., [25,1977] who estimated a 25 percent rate of return for direct and indirect R & D. Finally, Michael Evans [5,1976] in his study of contribution of NASA R & D expenditures to growth of aggregate productivity in the United States suggests a significant effect of R & D expenditures on growth of aggregate output and productivity through the inter-industry transmission of technical change.

From these studies, despite their differences and the ambiguity of some of their results, there seems to be some evidence for the indirect or spillover effects of R & D on growth of output and productivity. Also, there is evidence that linkages among industries determine the speed and magnitude of the indirect effects. The tentative implication is that in evaluating the contribution of R & D of an industry both the direct and indirect effects should be considered. However, because of the conceptual and empirical weakness of some of the past work, further studies of the spillover effects are needed to support more expanded government involvement in R & D efforts.

The Contribution of Government-Financed R & D

Government-financed R & D is concentrated in a few defense-oriented industries such as Air Transportation (missiles and space) (SIC 451), Electrical Machinery (SIC 36), Transportation Equipment (SIC 37), Ordnance and Instruments. There are some evidence, mostly negative, on the contribution of R & D financed by the Federal Government. Terleckyj reports that government-financed research (except in agriculture) had no direct effect on the productivity of the industries conducting it. There are some evidence that the indirect effect of government-financed R & D embodied in purchased inputs on the growth of output in the purchasing industries is very small. This was particularly true in the case of manufacturing industries, while in non-manufacturing industries, the evidence of indirect effects of government-financed R & D on growth of industrial output was not clearly established.

In another study, Griliches [11,1979] found a statistically significant but negative direct effect on productivity growth of the share of R & D expenditure financed by government. Total factor productivity in manufacturing was correlated with (1) the ratio of R & D to value added (a measure of research intensity) and (2) a dummy variable for a ratio of R & D expenditure to net sales of more than 15 percent to single out the research intensity of the Ordnance (SIC 19) and Aircraft and Guided Missiles Parts (SIC 372) industries where government-financed R & D is very high. The results suggest that concentrated, government-supported R & D leads to a decline in the growth of productivity. Similarly, in a different study using firm data, Griliches reports a strong depressing effect by publicly-supported R & D on the estimated rate of return. The two industries which are the major recipients of federal research funds, Electrical Equipment and Aircraft & Missiles had the lowest rates of return on R & D investment: 2 percent and 5 percent. In Chemical and Chemical Products and Fabricated Metals, the rates were about 90 percent and

25 percent, respectively.[4] However, unlike Terleckyj, Griliches calculates a positive but small indirect contribution to private productivity by government financed R & D.

Two features of publicly supported research in the United States should be noted. First, the large gains from public research in some industries, such as agriculture, are well documented. Second, half of all publicly financed R & D has been in defense and space. Excluding the portion of public expenditure on R & D going to defense and space industries, Griliches found some indirect productivity contribution by public expenditure on industrial research, on intramural federal research, and on research conducted at universities and non-profit institutes.

In a study evaluating the economic impact of NASA R & D spending, Michael Evans [5,1976] found a very significant effect by publicly-funded space R & D expenditures. Using a combination of macro-econometric and input-output models, Evans carried out two simulation exercises: one holding total government purchases constant but increasing NASA spending by $1 billion for one year and the other increasing the level of NASA R & D spending by $1 billion over a longer period of time. The results of the first simulation showed that simply changing the composition of government spending towards greater NASA spending redistributes demand from lower productivity to higher productivity industries. This shift results in a net increase of 20,000 jobs, higher productivity, and a lower rate of inflation. Under the assumption of sustained higher NASA R & D spending of one billion dollars per year will lead in 1984 to the following pattern of changes: 2.1 percent change in output, 0.8 percent change in employment, -2.2 percent change in consumer price index, 2.1 percent change in index of labor productivity, and -0.5 percent change in the unemployment rate. The key factors that make this possible are the increase in productivity due to a shift to high technology industries, such as the space industry, and a shift of demand away from industries with high rates of excess capacity. The rate of return to NASA spending, according to the Evans study, turns out to be about 38 percent.

This rate of return on government R & D is surprisingly high and in sharp conflict with results obtained using the micro-data sets noted earlier. There are some methodological and estimation problems that cast doubt on the accuracy and reasonableness of the results of this study. The estimates are extremely sensitive to small changes in estimation procedure and data classifications. The results of the study also lead us to a largely untenable, but enviable, public policy prescription. That is, by simply shifting the composition of the government budget, we can solve, to a large degree, the problems of growth, productivity, unemployment, and inflation simultaneously. Nonetheless, the Evans study is one of the few macroeconomic studies that directly assesses the impact of R & D expenditures on aggregate output utilizing a combination of the conventional macro and input-output models of the economy. The analytical framework of this study may be useful in further work. However, at present, it is not possible to compare the results obtained using macro and micro data. The data, models, and estimation techniques used in each study are quite different. The inconclusive nature of the evidence on the productivity of publicly funded R & D points to the urgent need for further study.

Private and Social Rates of Return

As noted earlier, the direct rate of return to R & D is very high when compared to other types of investment and the direct returns suggest that external benefits of R & D are even more impressive. For example, one study puts the direct rate of return to about 30 percent and indirect return to about 80 percent while another study suggest a median private rate of return of 25 percent and a median social rate of return of 56 percent. The crucial questions are what determines such divergence between the private and social rates of return and why the degree of this divergence differs among different industries. Current research does not provide adequate answers to these questions. However, a recent study by Mansfield et al. [25,1977] provides some evidence on these issues.

Their study indicates that the social and private rates of return vary greatly for different innovations. In about 30 percent of the cases, the private rate of return was so low that no firm, with the advantage of hindsight, would have invested in innovations, even though the social rate of return from these innovations was fairly high. The gap between social and private rates of return is often explained in terms of the market structure of the innovator's industry, i.e., whether the innovation is minor or major and whether the innovation is a new product or a procress. To be sure, other factors can also be responsible for this gap, but the statistical results of Mansfield's study [25,1977] indicate that the differences between the social and private rates of return tend to be greater for more important innovations and for innovations that can be imitated relatively cheaply by competitors. When the cost of initiating research is held constant it makes little difference whether the innovation is patented or not. These results are suggestive, but further research must be done before we can fully explain the substantial differences between social and private benefits of R & D.

Composition of R & D Expenditures and Growth of Productivity

The distribution of R & D expenditures is shifting away from basic research towards developmental research. These compositional shifts, accompanied by the relative decline of total R & D noted earlier, may affect the long-run growth of productivity in the U. S. economy. There is very little empirical evidence on the determinants of different types of R & D expenditures and on how they affect the growth of industrial output. How one stage of R & D leads to the other and with what time lag also remains largely unresolved.

There have been some studies, however, on the determinants of firm R & D for the purposes of designing new products. Several considerations may enter into a firm's decision to develop new products rather than improve existing products or methods of production. Such factors include the nature of the firm's existing product line, the riskiness of demand for these products in comparison with that anticipated for the new product, the potential entry of new competitors and rivalry with existing competitors, the size of the existing R & D program, and other industry characteristics. A study by Jon Rasmussen [35,1973] suggests that the anticipated demand for new products over a period of six years (as a measure of risk) positively affects R & D decisions for new product development. The more assured the growth of demand for existing products and the greater the profitability of the firm, the less motivation the firm has to attempt new product development. Conversely, more new products tend to be developed if the anticipated demand for them is sufficiently strong and the variability of demand for the existing product is high.

Unfortunately, very little research has been performed on issues related to compositional change in R & D expenditure (i.e., between basic, applied and development research) and its relationship to productivity growth. The implications of a shift in the composition of R & D expenditures away from basic research for the long-run growth of productivity (while total R & D expenditure relative to GNP is declining) requires close attention and careful assessment. Some of the questions which need to be answered are: (1) Just how much has the composition of R & D changed, and in which industries? (2) Are the changes from basic to applied research, or to development? How meaningful is the distinction between basic and applied research anyway? (3) Is the basic research a "pool" from which applied research draws, and does a decline in the growth of basic research lead to a decline in productivity of applied research? There is also an urgent need to explore the underlying processes and the factors that determine the relationship between basic and applied research and new product development.

II. FACTORS INFLUENCING R & D EXPENDITURES: PAST FINDINGS

In addition to the studies that estimate the contribution of R & D growth of output, a considerable amount of recent research has been devoted to finding which factors determine the magnitudes and patterns of R & D expenditures in different industries. The question here is whether and for how long growth of output, changes in relative prices and profits, degree of concentration, extent of regulation, etc. affect the level and rate of growth of R & D expenditures in different industries. Related issues are the pattern of causality that may exist between these variables and R & D decisions and the possible interactions of the existing structure of inputs with the accumulation of technical know-how or innovations.

The Input Demand Functions for R & D

The underlying hypothesis of studies on the demand for R & D expenditures is that R & D, like labor and capital, is considered to be an input in the production process and therefore subject to the influence of economic and technological considerations. The demand functions are derived by an optimization procedure and often estimated with such data as output, relative prices, profits, capital, and unemployment.

Most studies report a strong and positive relationship between R & D and output (sales) suggesting that growth of demand, especially if it is sustained over a period of time, stimulates innovative effort. Empirical evidence for the proposition that either liquidity or profitability is conducive to innovative effort is weak. There are studies, mainly using firm data, that assign an important role to cash flow variables in determing R & D expenditures; while other studies find no significant relationship.[5] However, where evidence of a positive relationship exists, cash flow variables seem to have their strongest effect on R & D during growth periods. This implies that anti-recessionary policies, such as lowering corporate income taxes or increasing depreciation allowances, would buttress R & D programs against cutbacks.

Surprisingly, very few studies, except those of M. Ishaq Nadiri and George Bitros [29,1979] and Rasmussen [35,1973], have examined the effect of relative input prices, such as cost of capital and wage rates, on R & D decisions. Both of these studies report evidence that relative prices affect R & D decisions both in the short and long runs. In the first study, the time response of R & D to changes in relative prices is found to be similar to that of investment in plant and equipment, i.e., price changes begin to affect R & D decisions after the second year. Rasmussen reports that R & D is sensitive to movements in the prices of labor and capital, and that a capital-saving bias is associated with industrial R & D effort. The evidence implies that public policy, by changing the relative prices through fiscal and monetary policies, could stimulate R & D effort.

<u>Firm Size, Concentration, and Inventive Activity</u>

It is often stated that large size and monopoly power are complementary in so far as R & D is concerned: the former influencing the breadth of the market for an innovation and the latter influencing its duration. It is also claimed that large diversified firms might undertake more research than small, single-product firms and that large, monopolistic firms would attract the best innovative talent. It is further argued that a certain critical size of an R & D program is required in order to realize positive returns, and that the minimum effort can best be undertaken by large firms.

The theoretical and empirical evidence of several studies on the relationship between the size of the firm and R & D effort as summarised by Morton Kamien and Nancy Schwartz [16,1975] indicates that the relationship is at best inconclusive, mainly due to the vagueness of the definitions of firm size, monopoly power etc. used in these studies. Also, more recent studies do not support a positive relationship between a firm's size and its R & D effort. Relating R & D expenditure to different measures of firm size, Griliches [11,1979] concluded that concentration ratios are generally unsatisfactory proxies for the extent of innovative rivalry in an industry. The relationship between R & D activity and industry concentration may also be non-linear. It may be that an intermediate market structure--between monopoly and perfect competition--is most conducive to R & D activity. To argue, therefore, the case for mergers simply on grounds of economies of scale in research would be incorrect unless it is to reach a threshold level below which R & D effort will be uneconomical to undertake.

Existing Factors of Production and R & D Decisions

The existing stocks of capital and labor probably affect both the level and the speed of adjustment of R & D expenditures in a firm. A highly capital-intensive firm may not be able to introduce new techniques which would make a large part of its existing capital obsolete. Also, the training and level of skills of the labor force can influence the R & D intensity of a firm. There are few studies exploring the relationships between the traditional factors of production and R & D expenditures. Nadiri and Bitros [29,1979], using a general disequilibrium framework, have analyzed the interactions among employment, capital stock, and stock of R & D. Using a sample of 114 firms, they found that R & D, capital, and labor not only respond to changes in output and relative prices but that there are strong interactions among them. The decision with respect to one input, such as R & D, is not independent of the firm's other input decisions and there is an interaction to and from other inputs as R & D, labor, and capital move toward long-run equilibrium values. They also found a strong effect of R & D expenditures on labor productivity both in the short and long runs. The implications of these findings are that a consistent policy be designed taking account of feedbacks among the inputs, and that a slowdown of the growth of productivity can be partially reversed if more R & D efforts are encouraged.

The Effects of Regulation

Where there is a possibility of natural monopoly due to the presence of economies of scale or an uncertainty of information on the part of consumers and a lack of incentive for firms to provide more adequate information, the forces of the free market will not ensure the proper amount or quality of goods and services at reasonable prices. These forces often lead to what is known as "market failures", and the regulatory bodies are assigned the task of regulating the amount and quality of goods and services to correct such failures. Whatever the merits of regulation on other grounds, there is evidence that the pursuit of regulatory objectives has contributed to an inhibition or distortion of technological innovation in several industries.

In the Pharmaceutical industry, according to several studies, the introduction of the Kefauver amendment in 1962 to FDA regulations has led to a sharp decline in the number of new chemical entities (NCE's) approved by the FDA in the period 1963-75. Martin Bailey's [1,1972] results show that the level of R & D expenditures necessary to generate a given flow of NCE's has more than doubled as a result of the 1962 amendment. Sam Pelzman's study [34,1974] of the industry before and after the 1962 amendment shows that the new regulations significantly reduced the flow of NCE's and indicates that the amendment may account for most of the difference between the pre- and post-1962 NCE flow.

Henry Grabowski, John Vernon, and Lacy Thomas' [8,1976] comparative study of the introduction of new pharmaceutical products in the United States and the United Kingdom shows that because of the stringent U.S. regulations, R & D productivity declined about six-fold between 1960-61 and 1966-70, while the decrease in the United Kingdom was about threefold. They also show that increased regulation roughly has doubled R & D costs per NCE in the United States. Further, the rising costs and lowered productivity of innovation in this industry has led to a shift in expenditures away from domestic R & D to foreign R & D by U.S. firms. Regulatory differences may also be at least partly responsible for the faster growth of R & D in pharmaceutical products in foreign countries and the acceleration of the U.S. drug firms' investments in manufacturing capacity abroad. Moreover, studies by Bailey [1,1972] and David Schwartzman [36,1976] show that there has been a sharp decline in private rates of return to R & D activity in the post-1962 period. Schwartzman's results also show a high variability in sales of NCE's since 1962 which is an indication that a significant "risk" premium is associated for new drug development throughout the post-amendment period.

Similarly, the study by Aaron Gellman [6,1971] on innovation in railroads concludes that regulation in railroad and truck transport has slowed down and distorted the pace and pattern of technological change. Roger Noll [33,1971] provides similar conclusions in the case of communications network. Paul MacAvoy and James Sloss [21,1967] show that an average of $9.4 million per year (1958-62) in potential cost-savings were lost through ICC-induced delays of adoptions of unit coal trains by the four major Eastern railroads.

The available studies generally point to the negative effects of regulation on the rate and timing of innovations. However, further studies are needed to explore in depth the trade-off between costs and benefits of regulation and to suggest ways of incorporating considerations that promote technological progress as part of the decision-making processes of the regulatory agencies.

<u>Summary</u>

Our discussion in the previous two sections point to the following tentative conclusions:

(1) There is evidence to confirm the findings of previous studies that R & D contributes positively to growth of output and productivity. The gross rate of return on R & D during the 1960's was very high--twice that of physical capital. Though little is known about the net return, the gross rate of return has remained fairly high, as we shall see, in the 1970's. The indirect or spillover effect of R & D from one industry to another is an important source of R & D contributions to growth of productivity.

(2) There is evidence that R & D inputs respond to changes in demand, relative prices, and existing input mix. There are interactive adjustments among R & D, employment, and capital.

(3) Judging from the results of the available studies, the effect of regulations on the timing and pace of R & D activities appear to be one of inhibiting the rate of technological change.

(4) Government-supported R & D contributes marginally to the measured growth of output and productivity. This may be due to the fact that government-financed R & D is concentrated in a few defense-oriented industries. Difficulties lie in measuring "output" in these cases. Another problem is the difficulty of measuring "output" of innovative activities. However, too little is known in this area to be very certain.

(5) A strong relationship between R & D intensity and firm size is not supported by the available evidence. Evidence on the relation between market structure and R & D performance is also inconclusive.

III. NEW ESTIMATES OF R & D CONTRIBUTIONS

Most of the studies mentioned in the previous two sections employed data from the 1960's though the investigations were carried out in the early 1970's. Their conclusions may be dated and may not be applicable to recent years. A closer look is needed at the 1970's data. Production functions will be used to evaluate the conclusions of the literature we have surveyed and to test some new hypotheses. To accomplish this, we have assembled data from different sources on eleven two-digit manufacturing industries for the period 1958-75. The data are classified into three samples of pooled cross-section time series data for "total manufacturing", "total durables", and "total nondurables".

Three main issues will be examined. The first issue is to explain the contribution of R & D input to growth of output and productivity over the entire period 1958-75 and the sub-periods 1958-65 and 1966-76. The sub-periods were chosen to see whether the contribution of R & D input to growth of output is different during the first period, when the rate of R & D expenditures was generally increasing, and the second period, when it was decreasing. Secondly, to identify the factors that may explain the behavior of the R & D input during these periods. The third task is to explore the effect of government-financed R & D on the private sector decision to undertake R & D expenditures. The question here is whether public financing of R & D positively or negatively affects private R & D expenditures.

The issue of assessing the contribution of R & D input to growth of output is addressed in this section by specifying and estimating a production function. The other two issues are taken up in Section IV where an input demand model for R & D is specified and estimated. Before presenting and interpreting results of our estimations, we shall describe briefly the nature of out data and the specification of the variables that are used in the econometric production and input functions.

Data and Specification of Explanatory Variables

Annual data on several variables were collected from a variety of sources indicated below for the period 1958-75 for the following eleven industries:

SIC CODE	Industry
Durables	
32	Stone, Clay and Glass
33	Primary Metals
35	Nonelectrical Machinery
36	Electrical Machinery
37	Transportation Equipment
Nondurables	
20	Food and Beverage
22	Textiles
26	Paper and Products
28	Chemicals and Products
29	Petroleum and Coal Products
30	Rubber and Plastics

The choice of industries was dictated by the availability of consistent time series data on R & D expenditures: "Total Durables" consists of the first five industries, "Total Nondurables" contains the remaining six industries, and "Total Manufacturing" includes all eleven industries. These pooled time-series cross section samples were designed to provide richer data to estimate the functions under consideration. The individual industry data are highly collinear and the resulting estimates would often be unstable and difficult to interpret. The production and R & D demand functions are estimated using an analysis of covariance technique developed by G. S. Maddala [22,1971].

The list of variables and their construction are:

(1) Q is a measure of output constructed from the industry value added data published in Census of Manufacturers [39,1977] and deflated by output price deflators given in Survey of Current Business [40,1977].

(2) (W/C) is the relative price variable where W is a measure of the price of labor and C is the user-cost of capital. W is measured by the average hourly earnings of production workers obtained from different issues of The Employment Situation published by the Bureau of

Labor Statistics (BLS). The user cost of capital is constructed following Jorgenson's formulation as:

$$C = \frac{p_k \ (\bar{r}+\delta) \ (1-\bar{k}-vz+vzk')}{(1-v)}$$

where p_k is the price of investment goods; $\bar{r}$ is the real rate of interest calculated as $\bar{r} = r - (\dot{p}/p)^e$, where r is the nominal rate of interest on Moody's Aaa-rated industrial bonds and $(\dot{p}/p)^e$ is the measure of expected inflation calculated as a weighted average of past changes in the consumer price index; δ is the rate of depreciation; $\bar{k}$ is the effective rate of investment credit; k' is the tax credit allowance under the Long Amendment, which required firms to subtract their total tax credit from their depreciation base. It is equal to $\bar{k}$ during the time when the Long Amendment was in effect and 0 at all other times; v is the corporate income tax; and z is the present value of the depreciation per dollar of investment of deductions.[6/]

(3) L is a measure of total employment excluding employment figures for scientists and engineers in each industry. Total employment figures are constructed by adding total production and non-production workers published in Employment and Earnings [41,1977] and the number of employed scientists and engineers reported in NSF publications.

(4) K_t is the measure of the net capital stock generated for each industry using the perpetual inventory formula

$$K_t = I_t + (1-\delta_1) \ K_{t-1} \ .$$

Here annual real investment, I_t, is taken from various issues of the <u>Survey of Current Business</u> [40,1977]; δ_1 is the depreciation rate and K_{t-1} is the benchmark capital stock. The depreciation rates and benchmark capital stock figures are taken from Bert Hickman [12,1965, Appendix B].

(5) R_t is the measure of the net capital stock of R & D. It is generated by a similar perpetual inventory formula, i.e.,

$$R_t = D_t + (1-\delta_2)\ R_{t-1}\ .$$

Here D is R & D expenditure deflated by the price index for investment in plant and equipment. The R & D figures for each industry are obtained from National Science Foundation (NSF) publications [31,1974; 32,1976]. The choice of the R & D deflator is certainly arbitrary but unavailability of the appropriate deflator for R & D permits little choice in this matter. It is extremely difficult to measure depreciation rates for stocks of knowledge. We arbitrarily picked a rate of 0.10 and assumed that it prevailed in each of the industries since there is no reliable information about depreciation of the stock of knowledge available to improve on this guess.

Benchmark figures for stocks of R & D are not available either for the aggregate economy or for individual industries. Some authors take the first available abservation on real R & D expenditure as the benchmark. This approach has certain shortcomings expecially if the rate of growth of R & D is rather slow. We have estimated the benchmark figures for R_{t-1} for each industry using the relation

$$R_0 = \frac{D_0}{\delta_2 + g}$$

where D_0 is the first year R & D expenditures in real terms and g is measured by the average growth rate of capital stock for the years succeeding the benchmark year. This approximation is used because of data translation.

(6) R_{p_t} is the measure of stock of private R & D and is generated in a similar way as R_t using the appropriate R & D expenditures series and the same values of δ_2. The private R & D expenditure figures are published by NSF [31, 1974].

(7) R_{g_t} is the measure of stock of government-financed R & D and is generated in a similar manner as R_{pt} using, however, the government-financed R & D figures published by NSF.

(8) U_t is a measure of the capacity utilization rate by industry taken from Wharton [42,1977].

Specification and Estimation Problems

To measure the contribution of R & D to growth of output, we used a simple three-input Cobb-Douglas production function of the form:

$$Q_t = AK_t^{\alpha_1}L_t^{\alpha_2}R_t^{\alpha_3}e^{\rho t} \qquad (1)$$

where ρ is the rate of exogenous technical change and t is time; other variables in equation (1) have been defined earlier. The Cobb-Douglas production function is a first-order approximation to higher-order logarithmic functions and is simple to interpret.

In estimating equation (1) using the cross-section time series data, we encountered estimation problems due to the high multi-collinearity among the variables. The pairwise correlations among K, L, R and t often were about 0.90. A consequence of the high degrees of multicollinearity among these variables is to make some of the variables look statistically insignificant when in fact they should be significant on theoretical grounds. This is what in fact turned out to be the case. The coefficients of employment, L, in each case was very large--above one, and the signs of the coefficients of K and R were sometimes negative and their magnitudes turned out to be statistically insignificant. The coefficient of the time trend also turned out to be statistically insignificant, and the fit of the equation was generally poor.

To meet this estimation problem, we have used the Ridge regression technique to estimate equation (1). Since this method is not very well known, it may be useful to explain some of its main features.[7/]

Consider the standard multiple regression model with N observation and K explanatory variables:

$$Y = X\beta + e$$

where β is a (K x 1) vector, X is (N x K) and of full rank. The expected values are $E(e) = 0$ and $E(ee') = \sigma^2 I$, where σ^2 is the population variance and I the corresponding identity matrix. The least squares estimate of β is given by $\overline{\beta} = (X'X)^{-1} X'Y$. Define the square of the distance from $\overline{\beta}$ to β by $D^2 = (\overline{\beta}-\beta)'(\overline{\beta}-\beta)$. The mean expected value of the square of the distance called the mean square error, is:

$$E(D^2) = \sigma^2 \text{Trace}(X'X)^{-1} = \sigma^2 \sum_{i=1}^{K} (1/\omega_i)$$

where the ω_i's are the eigenvalues of X'X.

If X'X is an ill-conditioned matrix with nonorthogonal data vectors and some small eigenvalues, the distance from $\overline{\beta}$ to β will be large. The least squares estimator is unbiased ($E(\beta) = \overline{\beta}$) and minimizes the residual sum of squares. However, utilizing both unbiasedness and minimum variance criteria, the results are not satisfactory in the presence of multicollinearity.

The ridge regression estimator reduces the distance from β to the estimator of $\overline{\beta}$, at the cost of an increase in the residual sum of squares. However, the greater the nonorthogonality of the matrix of regressors, the further one can move from the least squares estimator without an appreciable increase in the residual sum of squares. Minimizing the sum of squared errors subject to a constraint on the distance, yields the ridge regression estimator, given by:

$$\overline{\beta}^* = [X'X + \lambda I]^{-1} X'Y$$

where λ is a constant greater than zero.

The diagonal of X'X is augmented by a constant λ. Varying λ results in the estimation of the ridge trace.

The expected value of the distance is given by:

$$E[D^2(\lambda)] = E\{(\overline{\beta}^*-\beta)'(\overline{\beta}^*-\beta)\}$$

$$\sigma^2[\text{Trace } (X'X + \lambda I)^{-1} - \lambda \text{ Trace } (X'X + \lambda I)^{-2}] + \lambda^2\beta' \ (X'X + \lambda I)^{-2}\beta.$$

The first term is the sum of the variances of parameter estimates. The second term is the sum of the squares of the bias. Total variance decreases as λ increases, while the square of the bias increases with λ There exists a λ for which the mean square error is less than for the least squares estimator. The choice of the appropriate λ is arbitrary, so that a trace over a range of λ becomes of interest. Major considerations include the following: (1) the sum of squared errors should not be large relative to least-squares regression; (2) the systems should stabilize with some coefficients going to zero and all others become insensitive to small changes in λ; (3) coefficients with incorrect signs or unreasonable magnitudes should have been changed.

The Parameter Estimates and Their Stability

The production function (1) is estimated using the analysis of variance technique. Three sets of cross-section and time series data were employed. The estimated coefficients of the function are shown for three aggregate manufacturing industries in Table 1. Experimenting with the ridge regression technique, it was clear that at very small values of λ, the system of variables exhibited an orthogonal structure. The coefficient of the time trend, t, was often statistically insignificant; and, therefore, equation (1) was estimated without it.

As can be seen, the fit of the functions is quite good. The coefficients have the correct signs and all are statistically significant. The output elasticity of labor indicated in the second row of Table 1 ranges from 0.65 to 0.80 which is close to the share of labor, while the output elasticity of capital ranges from 0.22 to 0.36. However, the output elasticity of stock of R & D is much smaller compared to that of capital and labor in each of the three industries as would be expected. The magnitude of this elasticity is fairly high in Total Nondurables, perhaps reflecting the significance of R & D in chemical and petroleum industries. To test the sensitivity of the estimates, the production function was fitted using the stock of private R & D in place of the total stock of R & D. The result did not change much except that the coefficients of R & D variable in each of the sectors were somewhat larger when the stock of private R & D was used. Similarly, when we replaced our capital stock series by the series recently developed by John Kendrick [18,1973], the parameter estimates and the overall fit of the regressions changed very little.

Table 1. Generalized Least Squares Estimates of the Cobb-Douglas Production Function

Estimation Period: 1958-75

Estimated Equation

$$\ln Q_t = \alpha_0 + \alpha_1 \ln L_t + \alpha_2 \ln K_t + \alpha_3 \ln R_t$$

Independent Variables	Total Manufacturing $\ln Q_t$	Total Durables $\ln Q_t$	Total Nondurables $\ln Q_t$
Constant	0.37 (2.22)	0.50 (2.83)	--0.07 (1.14)
$\ln L_t$	0.65 (35.15)	0.82 (17.76)	0.70 (45.94)
$\ln K_t$	0.36 (21.80)	0.22 (8.73)	0.32 (17.31)
$\ln R_t$	0.11 (11.17)	0.08 (6.51)	0.19 (11.01)
R^2	0.94	0.98	0.99
SSR a/	219.7	95.8	121.0
λ b/	0.006	0.002	0.005

a/ Sum of squares due to regression.

b/ λ is a constant in the augmented $(X'X)^{-1}$ matrix, i.e., $[(X'X) + \lambda I]^{-1}$

The production estimates suggest that economies of scale prevail in each of the three industries. The sum of the coefficients of equation (1), $\mu = \alpha + \beta + \gamma$, provides an estimate of the magnitude of economies of scale. It is about 1.12 for Total Manufacturing, 1.11 for Total Durables, and 1.12 for Nondurables. The alternative hypothesis of constant returns to scale was rejected using a Chow-test. Basically, the estimates in Table 1 suggest that there are constant returns to scale with respect to the traditional inputs, i.e., capital and labor. That is, the production function can be written as

$$Q_t = AK_t^{\alpha_1} L_t^{(1-\alpha_1)} R_t^{\alpha_3} e^{\rho t} \qquad (2)$$

A statistical fit of this equation supported the hypothesis of constant returns to scale with respect to K and L.

From these results, it is quite clear that R & D contributes significantly to the growth of output over the period 1958 to 1975. The output elasticity of stock of R & D is estimated to be 0.11 in Total Manufacturing, about 0.075 in Total Durables, and approximately 0.19 in Total Nondurables. These estimates of the gross rates of return on stock of R & D (calculated as $\psi = \alpha_3(\overline{Q/R})$ where α_3 is the coefficient of R in each of the production functions and $(\overline{Q/R})$ is the average ratio of output to R & D stock) for the period are: 0.20 for Total Manufacturing, 0.12 for Total Durables, and 0.86 for Total Nondurables. The substantial difference in the rates of return to R & D in the durables and nondurables sectors is partly due to the differences in the output elasticities of R & D but more importantly is due to the large differences in Q/R ratios in the two industries; the growth of stock of R & D compared to growth of output in nondurables has been very small in spite of the fact that some nondurables industries such as chemicals have experienced high rates of growth of R & D in the postwar period.

Another issue that arises here is whether these estimates are stable over time. It is likely that the structure of the production process might have changed at some point during the period of estimation and the decline in R & D expenditure since 1966 may be a response to such a change. To test the stability of the production function over time, we fitted the function to several sub-periods: 1958-62, 1963-67, 1968-72, and 1973-75, as well as to samples of data covering the periods 1958-65 and 1966-75. Selection of the exact time when structural changes might have occurred is always difficult and arbitrary. Nonetheless, checking the stability of the coefficients and fit of a function over several sub-samples is an appropriate test.

To save space, we have presented in Table 2 the parameter estimates of the production function for each of the industries for the periods 1958-65 and 1966-75. The estimates in Table 2 clearly indicate that the values of the parameters of the production function hardly change over the two periods. The estimates obtained by fitting the model to data for the four sub-periods mentioned also exhibit stability and the magnitudes of the coefficients are similar to those indicated in Table 2. We conclude that the parameters of the production function are highly stable. Thus, the substantial reduction in R & D expenditures since 1966 has had no effect on the stability of the coefficients. Neither has the gross rate of return on stock of R & D changed substantially since 1966. The values of ψ calculated for the two periods for each of the industries are indicated in Table 3. The reason for the stability of ψ

Table 2. Generalized Least Squares Estimates of the Cobb-Douglas Production Function

Estimation Period: 1958-65 and 1966-75

Estimated Equation

$$\ln Q_t = \alpha_0 + \alpha_1 \ln L + \alpha_2 \ln K_t + \alpha_3 \ln R_t$$

Independent Variables	Total Manufacturing $\ln Q_t$ 1958-1965	Total Manufacturing $\ln Q_t$ 1966 1975	Total Durables $\ln Q_t$ 1958-1965	Total Durables $\ln Q_t$ 1966 1975	Total Nondurables $\ln Q_t$ 1958-1965	Total Nondurables $\ln Q_t$ 1966 1975
Constant	0.10 (0.77)	0.55 (2.30)	0.72 (3.48)	0.72 (2.82)	-0.14 (-1.14)	-0.05 (-1.69)
$\ln L_t$	0.65 (38.98)	0.63 (29.63)	0.77 (23.75)	0.75 (13.52)	0.69 (39.45)	0.71 (57.88)
$\ln K_t$	0.38 (26.64)	0.35 (16.86)	0.22 (15.14)	0.23 (7.42)	0.33 (17.95)	0.33 (20.95)
$\ln R_t$	0.11 (13.26)	0.11 (9.47)	0.08 (10.38)	0.09 (6.96)	0.18 (11.13)	0.18 (11.36)
R^2	0.98	0.94	0.99	0.98	0.99	0.99
SSR a/	114.18	137.19	51.01	60.09	57.95	73.96
λ b/	0.001	0.001	0.001	0.001	0.001	0.001

a/ Sum of squares due to regression.

b/ λ is a constant in the augmented $(X'X)^{-1}$ matrix, i.e., $[(X'X) + \lambda I]^{-1}$

Table 3. Gross Rates of Return on R & D in the Manufacturing Industries for the periods 1958-65 and 1966-75[a]

Industries	1958-65	1966-75
Total Manufacturing	0.22	0.20
Total Durables	0.10	0.12
Total Nondurables	0.86	0.85

a/ The value of ψ is calculated by $\alpha_{3i}^{*}(Q/R)_i$, where α_{3i} are regression coefficients of stock of R & D for industry i in Table 2 and $(\overline{Q/R})_i$ are the associated average value of the ratio of output to the stock of R & D.

in each of the sectors in the two periods is that the output elasticities shown in Table 2 have not changed and that $(\overline{Q/R})_i$ has also remained fairly stable. The latter is explained by the slowdown in the growth of the stock of R & D having been accompanied by a similar slowdown in growth of output in the period 1966-75.

However, the reduction in R & D expenditures since 1966 has greatly reduced the growth of the potential output in these industries. The average annual growth rates of the stock of R & D and real R & D expenditures over the periods 1958-65 and 1966-75 for the three industries were:

	Growth of Stock of R & D		Growth Rate of R & D Expenditures	
	1958-65	1966-75	1958-65	1966-75
Total Manufacturing	0.07	0.03	0.065	0.017
Total Durables	0.08	0.03	0.070	0.027
Total Nondurables	0.07	0.04	0.065	0.007

These figures indicate that a substantial decline in rates of growth of both R & D expenditures and stock of R & D input has occurred during these two periods. An important factor contributing to these declines has been a substantial cutback in public funding of R & D in most of the durable and nondurable industries.

Tentative estimates of how much extra output would have been generated in each of the industries (assuming everything else remains the same), if the rate of R & D expenditures had not declined since 1966, could be obtained by the following mental experiment. Suppose the stock of R & D for the three industries had increased during 1966-75 at the same average rate as for the period 1958-65. Let us assume also that the growth of other inputs would not be affected by the faster growth of R & D input and that the parameters of the production function (1) remained stable between the two periods and their estimated values were equal to those shown for the 1958-65 period. Our calculations suggest that the yearly output would have grown by 0.005 for Total Manufacturing, 0.004 for Total Durables and 0.006 for Total Nondurables.

These estimates should be interpreted carefully and only as an exercise; the underlying assumptions for these calculations are extremely weak, especially the notion that the parameter estimates for other inputs would remain the same if the stock of R & D had grown substantially; the complementarity among the inputs, K, L and R precludes such a possibility. However, as an exercise these figures suggest substantial loss of potential output due to decline in R & D spending. The potential loss is much greater when we note that all manufacturing industries are not included in our samples and that the indirect or spillover effects on other industries are excluded as well.

IV. A MODEL OF R & D INPUT DEMAND

In the previous section we assumed that the quantities of all the inputs--labor, capital, and stock of R & D--were given and explored the contribution of stock of R & D to growth of output. However, there is also the question of what determines the R & D expenditures. Elsewhere, we have developed a complete model of interrelated input demand functions where the determinants of all three inputs are specified and estimated.[8/] Here, we shall concentrate only on the demand function for R & D deduced from the complete model.

A Derived Demand Model

Using the general disequilibrium input demand model developed by Nadiri and Rosen [30,1973], we can formulate the R & D input function as:

$$\ln R_t = \beta_0 + \beta_1 \ln Q_t + \beta_2 \ln(\frac{W}{C})_t + \beta_3 \ln L_{t-1} + \beta_4 \ln K_{t-1}$$
$$+ \beta_5 \ln R_{t-1} + \beta_6 \ln U_{t-1} \qquad (3)$$

where R_t is the stock of R & D, Q the level of output, (W/C) the ratio of wage to user cost of capital, L_{t-1} the lagged value of employment, K_{t-1} the lagged value of capital stock, R_{t-1} the lagged values of the dependent variable and U_{t-1} is the lagged value of the utilization rate. This equation is one of a system of four equations which includes the production function (1) and two input equations for capital and labor similar in structure to (3).

The interpretation of equation (3) is that the desired and hence the actual stock of R & D is affected by the level of output and by movements in relative prices. Unfortunately, it is not possible to construct a price variable for R & D input, and we have made the arbitrary but convenient assumption that the R & D input price can be approximated by the user-cost of physical capital. The other variables that influence the behavior of R & D in (3) are the lagged values of all factors of production. The lagged values, L_{t-1} and R_{t-1}, depict dynamic forces which affect the adjustment path of R & D to its equilibrium or desired level. That is, whenever there is a disequilibrium in quantities of labor or capital (i.e., the actual values are different from their optimum levels) the firm's decision with respect to R & D is affected. Whether R & D expenditures increase or decrease when there is disequilibrium in the firm's input levels of capital and labor depends on the complementary or substitutional relationships that may exist between R & D and capital or R & D and labor. Thus, the sign of the coefficients of $\ln L_{t-1}$ and $\ln K_{t-1}$ in equation (3) can be positive or negative depending on the relation of R & D with K and L in the production of output. Finally, R & D decisions may be influenced by business cycle developments, i.e., when business is expanding, firms increase their R & D expenditures while in periods of recession they may decrease or postpone such expenditures. The capacity utilization variable, U_{t-1}, in equation (3) is to account for these developments.

The rationale for the existence of the dynamic forces in equation (3) requires some explanation. The underlying hypothesis is that the firm must incur some costs over time to change its inputs. When the firm attempts to adjust one of its inputs, the adjustment of its other inputs is affected because the adjustments of the inputs are interdependent if the firm is to remain on its production function. For example, if the firm increases its capital stock, it would create the need to increase its stock of knowledge and to increase of decrease the size of its employment. Thus, there is a feedback system among the inputs, and as the firm attempts to meet its demand, this feedback process traces the dynamic adjustment path of each input.

Equation (3) was estimated by both the generalized least squares and the two-stage least squares procedure to take account of the simultaneous relations that exist between R and output Q. The coefficients of equation (3) were not sensitive to the choice of estimation technique, and therefore only the estimates generated by the two-stage least squares technique are shown in Table 4. As can be seen from that table, equation (3) provides a very good explanation of the behavior of total R & D in all three aggregate industries. The fit of the equations is quite good and the coefficients of the explanatory variables have the expected signs and are statistically significant. The estimates indicate that changes in output and relative prices affect R & D in the short run

Table 4. The Determinants of Total R & D Expenditures
Estimation Period: 1958-75

Estimated Equation

$$\ln R_t = \beta_0 + \beta_1 \ln Q_t + \beta_2 \ln(W/C)_t + \beta_3 \ln L_{t-1} + \beta_4 \ln K_{t-1} + \beta_5 \ln R_{t-1} + \beta_6 \ln U_{t-1}$$

Independent Variables	Total Manufacturing	Total Durables	Total Nondurables
Constant	0.34 (1.87)	0.45 (2.05)	-2.07 (5.57)
$\ln Q_t$	0.05 (3.28)	0.08 (4.62)	0.04 (1.96)
$\ln(W/C)_t$	0.16 (3.76)	-0.12 (2.41)	0.56 (8.95)
$\ln L_{t-1}$	-0.09 (3.62)	-0.05 (1.85)	-0.13 (3.59)
$\ln K_{t-1}$	0.06 (5.00)	0.03 (1.72)	0.14 (8.17)
$\ln R_{t-1}$	0.84 (68.85)	0.89 (68.29)	0.88 (34.99)
$\ln U_{t-1}$	0.04 (1.79)	0.04 (2.12)	0.18 (4.34)
R_2	0.97	0.98	0.94
SSR[a/]	189.80	79.86	100.81
λ[b/]	0.00	0.00	0.00

a/ Sum of squares due to regression.

b/ λ is a constant in the augmented $(X'X)^{-1}$ matrix, i.e., $[(X'X) + \lambda I]^{-1}$ However, the equations in the table were estimated without resort to the ridge regression technique.

except in the category of Nondurables where the effect of changes of output in the short run is statistically insignificant. Surprisingly, relative price changes exert very significant effects, particularly in Nondurables. This may be due in part to collinearity between relative price and output as real wages in natural as opposed to efficiency units have tended to rise relative to the user cost of capital along with output.

The signs of the coefficients associated with labor and capital suggest that a disequilibrium in employment leads to a reduction in R & D investment, while a similar phenomenon in physical capital leads to an increase in R & D expenditure. That is, there is a substitutional relationship between employment and R & D and a complementary relation between R & D and capital stock of the firm. These feedback or cross-adjustment effects are fairly strong and statistically significant. Also, it seems that the average adjustment lags between actual and desired levels of R & D are fairly long--over five years in each of these aggregate industries.

Finally, the degree of capacity utilization influences the stock of R & D positively and significantly, the main effect of capacity utilization on R & D input being felt in the Nondurables sector. The results support the notion that in the expansionary phase of the business cycle, expenditures on R & D are often increased; while in contractionary phase, such expenditures are generally reduced.

The results shown in Table 4 suggest several possibilities for public policy to promote R & D activities. For example, if the fiscal and monetary policies promote sustained growth of the economy and avoid business cycle fluctuations; or if through tax policies the relative prices are changed, R & D expenditures will increase. Also, public policy should recognize the interdependence that exists at least in the short run between different inputs. For instance, a vigorous R & D program may lead to an increase or decrease in investment in plant and equipment or in the level of employment; these indirect effects need to be considered when formulating public policy. Further, the results indicate that fairly long and complicated adjustment lags are involved as R & D adjusts over a period of time. The intertemporal adjustment of R & D is intertwined with that of other inputs and not recognizing this could lead to erroneous decisions.

The Effect of Government-Financed R & D

As we noted earlier, some believe that public and private R & D are complementary with each other, i.e., when opportunities for new innovations arise, public funding enables firms to exploit these opportunities better than if they were to finance the whole undertaking from their own funds. Others argue that firms cut back their own financing of R & D when public funding becomes available. Which of these hypotheses is correct is important for public policy.

We now examine the relationship between publicly funded R & D and privately financed R & D in the three aggregate industries. The same basic model of determinants of R & D as described by equation (3) is utilized to investigate the issue. The modifications that are introduced are: the dependent variable is now the stock of privately financed R & D, R_p, and the stock of government-financed R & D, R_g, is added to the independent variables on the right hand side of equation (3). The underlying hypothesis is that firms in principle accumulate two types of stock of knowledge; one financed from their own funds and the other through government financing. We have assumed that government-financed R & D is exogenously given.

The results are shown in Table 5. Due to unavailability of suitable data, the sample period for these equations is shorter (1969-75) than before, and Total Nondurables comprises only five industries instead of six. Further, we have made some crude assumptions to generate the series for the stock of government and privately financed R & D.[9/] The results in Table 5 are, in general, similar to those presented in Table 4. Privately financed R & D is influenced by changes in demand and relative prices. The effects of changes in capital and labor are also strong and statistically significant, and the business cycle effect, captured by the capacity utilization variable, also exerts strong effects except in the durable industries.

The effect of government financed R & D on private R & D differs by sector according to the results in Table 5. Based on the data in our sample, it seems that growth of publicly financed stock of R & D has a positive and statistically significant effect on both Total Manufacturing and Total Durables, while its effect is statistically significant and negative in Nondurables. These estimates suggest that whether recent slowdown of government R & D expenditures affects the growth of private R & D in the aggregate economy depends mainly on the industry composition. When publicly financed R & D was lagged one year, its coefficient turned out to be statistically insignificant. This suggests that the effect of government financing of R & D on private R & D decisions is felt within the year. It should be pointed out, however, that the aggregate nature of the data probably conceals the true timing relationship between government-financed and private R & D decisions.

Table 5. The Determinants of Privately Financed R & D Expenditures
Estimation Period: 1960-75

Estimated Equation

$$\ln R_t = \gamma_0 + \gamma_1 \ln Q_t + \gamma_2 \ln(W/C)_t + \gamma_3 \ln L_{t-1} + \gamma_4 \ln K_{t-1} + \gamma_5 \ln R_{g_t} + \gamma_6 \ln R_{p_{t-1}} + \gamma_7 \ln U_{t-1}$$

Independent Variables	Total Manufacturing	Total Durables	Total Nondurables
Constant	-1.01 (4.36)	-0.70 (3.00)	-1.02 (2.81)
$\ln Q_t$	0.05 (3.78)	0.11 (6.42)	0.03 (1.48)
$\ln(W/C)_t$	0.27 (5.63)	0.01 (0.23)	0.39 (5.72)
$\ln L_{t-1}$	-0.07 (2.81)	-0.01 (1.39)	-0.03 (1.82)
$\ln K_{t-1}$	0.08 (6.41)	0.04 (3.11)	0.07 (3.68)
$\ln R_{g_t}$	-0.01 (2.25)	0.04 (4.34)	-0.02 (3.44)
$\ln R_{p_{t-1}}$	0.92 (61.54)	0.87 (45.39)	0.85 (27.59)
$\ln U_{t-1}$	0.07 (3.35)	0.02 (0.75)	0.12 (2.71)
R^2	0.97	0.99	0.96
SSR[a/]	153.7	67.9	70.0
λ[b/]	0.00	0.00	0.00

a/ Sum of squares due to regression.

b/ λ is a constant in the augmented $(X'X)^{-1}$ matrix, i.e., $[(X'X) + \lambda I]^{-1}$ However, the equations in the table were estimated without resort to the ridge regression technique.

V. SUMMARY AND CONCLUSIONS

From the estimates of the production and input functions we discussed in Sections III and IV, certain conclusions emerge:

(1) Contributions of R & D input to growth of output and productivity are substantial in all three major industry sectors although the size of the contributions differs by sectors.

(2) The magnitude of the output elasticities of R & D input has remained fairly stable over the period 1958-75, though the slower rate of growth of R & D expenditures since 1966 has contributed to the slower growth of potential output since then. The gross rates of return on stock of of R & D have not increased in the 1966-75 period because of slower growth of both output and R & D input.

(3) Changes in output and relative input prices do influence R & D activities which are also influenced by cyclical fluctuations of the economy and by changes in the stock of physical capital and in the employment level.

(4) The effect of government financing of R & D on private decisions regarding R & D expenditures differs among different industries. Our results are basically inconclusive on whether government-supported R & D affects positively or negatively the growth of output.

Among the many issues that require further considerations are the processes and effects of public and private cooperation in funding new R & D, the role and method of public funding in areas where R & D is needed, (e.g., pollution control, housing, urban transportation, energy), and the relationship between the changes in the composition of R & D expenditures (basic, applied, and developmental) and growth of productivity.

Extensive research on the influence of government regulations on the rate and timing of innovations and much further examination of the structural relationships between R & D expenditures, production of knowledge, patents, growth of output and productivity are also called for.

The list could be extended. However, the most important barriers to further research into these areas of inquiry are the inadequate state of data and the poor conceptual framework of our models. Better macro and micro data are needed. The measurement errors of the available data are substantial. Careful study of these data, reduction in measurement errors, and new bodies of data are necessary. Considerable progress is also needed at the conceptual level to understand how knowledge differs from and interacts with other production inputs and how this influences the productive process over time.

FOOTNOTES

1. See for further discussion Edwin F, Denison [3,1974], Dale Jorgenson and Zvi Griliches [15,1967], John Kendrick [17,1973], Charles Kennedy and A.P. Thirlwall [19,1972], and M. Ishaq Nadiri [27,1970].

2. For a sample of these studies, see Nestor Terleckyj [37,1959]; 38,1974], Zvi Griliches [9,1964], Edwin Mansfield [23,1965], Jora Minasian [26,1969], Murray Brown and Alfred Conrad [2,1967].

3. This correlation is positive, strong, and on the average begins in the second year after R & D investment, continuing to rise steadily for at least nine years after the initial input years, reflecting the rising proportion of sales of new products developed through R & D. See William Leonard [20,1971].

4. Zvi Griliches [11,1979] has found a somewhat higher elasticity (10%) for research-intensive industries (Chemical and Allied Products, Primary Metals Industries, Electrical Equipment, Motor Vehicle and Equipment, and Aircraft & Guided Missiles) and a lower elasticity (4%) for other industries.

5. For further discussion, see Henry Grabowski and Dennis Mueller [7,1977], J.W. Elliot [4,1971], and J.D. Howe and D.G. McFetridge [14,1976].

6. For details of constructing the user-cost of capital and source of data, see M. Ishaq Nadiri [28,1972].

7. For further description of this method, see A.E. Hoerl and R.W. Kennard [13,1970].

8. See for further details and specifications, M. Ishaq Nadiri and Sherwin Rosen [30,1973].

9. See pp. 20-24 for construction of these variables and sources of data.

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