THE CONTRIBUTION OF RESEARCH AND DEVELOPMENT
TO ECONOMIC GROWTH

by

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Introduction

Technical progress results from a combination of research, development, invention, and innovation; the spread of technology depends on its pattern of diffusion and rate of adoption; and the result of technical progress is an increase in the quantitative and qualitative growth of the economy. Several years ago, Professor Edwin Mansfield summarized very ably the state-of-the-art on the contribution of research and development (R & D) to economic growth in the United States. He reported the contributions and weaknesses of various studies and posed some questions for further research. The tasks before us are to assess the state-of-the-art since Mansfield's summary, determine how much of subsequent research has confirmed his observations or answered his questions, note the emergence of new questions and new types of research in the field, consider the methodological and statistical weaknesses of results reported since 1970, and frame some questions for future research.

These issues take on added significance since the rate of growth of total R & D in the U.S. has slowed down considerably in the 1970's; R & D is no longer a growth industry. From 1953 to 1961, R & D expenditure in real terms increased at an average of 13.9% a year for government and 7.7% for non-government sources; from 1961 to 1967, these growth rates were decidedly lower, 5.6% for government-funded and 7.4% for private R & D; but from 1967 to 1975, the growth rates of government and private R & D expenditures shrunk to 3% and 1.8%, respectively. The studies summarized below
may provide some clues to the important questions: Why has such a precipitous decline in R & D expenditures occurred? and, What will be the ramifications of this slow-down on the future growth of the U.S. economy?

Our discussion will proceed along the following lines. Current questions regarding the behavior of R & D and its contribution to economic growth are stated in Section 1. In Section 2, the relationships between R & D and productivity increase in individual industries and firms are discussed and evaluated. The determinants of research intensity or R & D expenditures are examined in Section 3; the relationship between research intensity and size of the firm is explored in Section 4. The effects of regulation on innovation, especially pharmaceutical innovation, is considered in Section 5. In Section 6, the evidence on private and social rates of return is reported. The relation of changes in the composition of R & D expenditures to productivity growth is discussed in Section 7, and the measurement problems, evaluation of results, and areas for further research are discussed in Section 8, the concluding section of this brief report. We shall not, however, comment on the diffusion of technology or the interrelationships between research, development, innovation, and invention. Issues related to the international transfer of technology and its impact on the U.S. economy will, likewise, not be included in our discussion. Also, since most of the new research on the subject has concentrated on the relationship of R & D and productivity on industry and firm levels, we shall not comment extensively on this relationship at the aggregate economy level, which was a highly active area of research in the 1960's.
1. Some Questions About the Role and Behavior of R & D in Economic Growth

To begin with, it is interesting to note some changes in the pattern of R & D expenditure in recent years and the questions they raise:

1) The biggest spender of R & D funds is still private industry, though the foremost source of R & D financing is the Federal Government. This dichotomy is due to the massive defense contracts negotiated between government and industry. Further, the distribution of R & D among different industries is quite uneven, and the pattern has not changed substantially in the 1970's. The relevant questions in this connection are: What is the effect of government-financed R & D on the private sector's growth of productivity? Does the industrial mix of R & D expenditure have a negative effect on the rate of growth of productivity?

2) The private and social rates of return on private industrial R & D expenditure were documented to be very high in the 1960's, and the presence of these high rates has been confirmed by studies published in the 1970's. Several interesting questions arise: If the rates of return are so high, why is it that greater amounts of resources do not flow into R & D activities? How can the persistence of high rates of return and a decline in real R & D expenditure, as noted above, be reconciled? Does this phenomenon imply that the U.S. is underinvesting in R & D activities? What are the factors which account for the persistent difference between social and private rates of return?

3) Since growth of productivity is positively correlated with R & D expenditure, it is important to know what determines R & D expenditure in the first place--particularly, are R & D expenditures sensitive to changes in relative input prices, such as tax incentives? Also, does R & D expenditure affect a firm's level of employment and physical capital expenditure?
Are there economies of scale in R & D expenditure, i.e., is R & D related to the size of the firm? Finally, what role do financial variables such as cash flow and profitability play in determining the rate of growth of R & D expenditure? In fact, the R & D expenditure process has not been adequately integrated into a comprehensive model of the firm's resource allocation decision-making; such a model, when properly specified, would reflect the dynamic and interactive nature of this process.

4) The composition of R & D between basic, applied, and developmental types of research has changed quite visibly in recent years away from basic and applied to developmental research; the decline in basic research as a percentage of total R & D expenditure since 1963 has been dramatic. The questions arising are: What is the relationship between the composition of R & D expenditure and growth of productivity, i.e., what are the contributions of various types of R & D to productivity growth at the industry and firm levels? What might be the factors that determine the division of resources among these types of research? What are the interrelationships between these stages of R & D? Is there evidence of underinvestment in any or all of these types of research activities?

5) It has been argued that government regulation has been a major impediment to innovation in some industries, notably the pharmaceutical, transportation, communications, and energy industries. These regulations, it is claimed, have distorted, inhibited, and delayed technological innovation in the industries affected. Does the evidence support these claims? What have been the timing of these regulations and the magnitude of their effects on innovation? What novel governmental policies might be designed to promote technical progress in the regulated industries?
2. The Contribution of R & D to Growth of Productivity

Mansfield's summary and evidence provided by other researchers suggested a positive and significant contribution by R & D expenditure to the rate of output growth in a variety of industries during the period 1955-1970. More recent studies confirm these findings. W. Leonard, analyzing 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) in seventeen two-digit industries, 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. 4

Similar results on the direct effect of research intensity on industrial growth have been obtained by N. Terleckyj, using a sample of 33 industries. 5 Growth in total factor productivity for the period 1948-1966 was related to non-R & D variables, such as percent of sales to the private sector, degree of union membership, annual rate of cyclical change in output, 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 by privately-financed R & D on growth of factor productivity and no discernible effect by government-financed R & D. The explanation may be that government R & D can be viewed as a distinct output of the performing industry, rather than--and in contradistinction to privately-financed R & D-- an investment in its productivity. The contribution of firm-financed R & D to growth of productivity was calculated at .36%. 
Also, the effects of R & D expenditures on growth of productivity in manufacturing and non-manufacturing industries were considerably different. Z. Griliches obtained similar results, using census data for 883 large R & D-performing companies divided into six industrial groupings. Growth of productivity was found to depend significantly on both R & D and capital stock, and some diminishing returns to the absolute size of the research program and a negative impact of variability in it were indicated. Again, there were significant differences found among the industries in the contribution of R & D.\textsuperscript{6}

2.1 Effects of R & D Embodied in Purchased Goods

Productivity in a given industry can increase through 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 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 in agriculture and pre-fabricated structures in the construction industry, contribute greatly to the productivity of the industries using them. These indirect or "spill-over" 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. N. Terleckyj has estimated the intensity of R & D embodied in purchased goods for 33 manufacturing and non-manufacturing industries for the period 1948-1966.\textsuperscript{7} The results indicate a strong effect by R & D-intensive purchased inputs on productivity growth: rates of return of 45% in
manufacturing, 62% for total industries, and 187% for non-manufacturing are attributed to the indirect effect of R & D through purchased inputs; Terleckyj set the estimated indirect effect of private R & D at 80%, more than twice the direct rate of return of 30%. These results are in contrast to the estimates obtained by Griliches, which are 20% each for direct and indirect R & D, and to rates of return obtained by Mansfield, et al., who estimated a 25% rate of return for direct and indirect R & D. Finally, the Chase Econometrics study also implies a significant effect by R & D on growth of aggregate output and productivity through the inter-industry transmission of technical change.

It is clear from these studies, despite their differences, that the indirect or spill-over effects of R & D expenditures are at least as important as their direct effects and that the input-output relationships among industries determine the speed and magnitude of the indirect effects. The implication of these results is that policy should not be based solely on the direct effects of R & D in a given industry, but take account of its secondary effects that work through the industrial input-output structure. Large indirect effects presumably strengthen the case for public support of expansion of private R & D investment on the grounds of its contribution to over-all economic growth. This argument is related to, but not the same as, the argument for support on the basis of social return not captured by the originating firms (and resulting in underinvestment), or the argument for support in order to narrow the distribution of risk.

2.2 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), Electric
Machinery, Transportation Equipment, Ordnance, and Instruments. There is some evidence, mostly negative, on the contribution of R & D financed by the Federal Government. Terleckyj reports that government-financed research (except in agriculture) has no direct effect on productivity of the industries conducting it. There was also some evidence that the indirect or spill-over effect of government-financed R & D embodied in purchased inputs was little or nothing on the growth of output in the purchasing industries. This was particularly true in the case of manufacturing industries, while in non-manufacturing industries the evidence of no indirect effect by government-financed R & D on growth of industrial output was not clearly established.

In another study, Griliches found a statistically significant but negative direct effect on productivity growth by the share of R & D expenditure financed by government. Total factor productivity in manufacturing was correlated to (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%—this figure being the research intensity for Ordnance (SIC 19) and Aircraft and 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 and Missiles, had the lowest rates of return on R & D investment, 2% and 5%, while in Chemicals and Metals the rates were about 90% and 25%, respectively. However, unlike Terleckyj, Griliches calculates a
positive but small indirect contribution to private productivity by government R & D.

Measuring the effects of publicly-supported research is very difficult, indeed. Two points 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, intramural federal research, and universities and institutes in 1970. In a recent study of the economic impact of NASA R & D spending, Michael Evans of Chase Econometrics found a very significant effect by publicly-funded space R & D expenditures. Using a joint macro-econometric and input-output model, Evans carried out two simulation exercises, one holding government expenditures the same but shifting one billion dollars to NASA spending, and the other increasing the level of NASA R & D spending by $1 billion over a long period of time. The results of the first simulation show that simply changing the composition of government spending towards greater NASA spending redistributes demand from low productivity to higher productivity industries. The main results of this simulation are a net increase of 20,000 jobs, higher productivity, and a lower rate of inflation. The second simulation, under the assumption of sustained higher NASA R & D spending, leads, in 1984, to a 2% increase in output, a drop of 2% in the rate of inflation, a 2% increase in productivity, and an increase in employment of about .8 million. 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 Chase study, turns out to be about 38%. This rate 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. However, this is one of the few macro-economic studies of the impact of R & D expenditures available, and it indicates the lines along which further studies could be done. 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.

3. Determinants of R & D Expenditures

In addition to studies that estimate the contribution of R & D to growth of output, other recent studies have attempted to explain the determinants of R & D expenditure or R & D intensity at the firm and industry levels. The underlying hypotheses are: one, that R & D, like labor and capital, is an input in the production process and is therefore, influenced by variations in the rate of output and relative input prices; two, that input decisions are related to decisions with respect to employment and capital investment; and, three, that there is also an interdependency between R & D and profitability of the firm—the rate of innovation shapes and is shaped by profit opportunities and the availability of resources.

Branch, after examining the direction of the relationships "sales to R & D" and "R & D to profit," finds that R & D activity tends to increase
both profits and growth of output, but finds somewhat weaker the "profit stimulates R & D" hypothesis. Nadiri and Bitros, using a sample of 114 firms, find that R & D and other factors of production, such as labor and capital, not only respond to changes in output and relative prices of inputs: there are strong interactions among them. These interactions trace the dynamic adjustment path of each input to its long-run equilibrium value. The conclusion reached by this study is that a decision with respect to R & D is not independent of the firm's other input decisions and that there is an interaction or spill-over effect to and from other inputs which should be taken into account.

Surprisingly, very few studies, except those of Naditi and Bitros and Rasmussen, 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 of the effect of relative prices on R & D decisions, both in the short and long runs. In the first study, the response of R & D to changes in relative prices is found to be similar to that of investment in plant 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 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 promoting low wage rates and capital costs, could stimulate R & D effort.

Also, several recent studies confirm the results of previous studies on the significance of sales (or output) and cash flow variables in the decision to invest in R & D. The strength of these variables in explaining R & D decisions varies significantly across industries, however. 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, exerts a positive influence on innovative effort.\textsuperscript{18} Empirical evidence for the proposition that either liquidity or profitability is conducive to innovative effort is not very strong. There are studies, mainly using American firm data, that assign an important role to cash flow variables in determining R & D expenditure,\textsuperscript{19} while other studies find no significant relationship.\textsuperscript{20} However, where evidence of a positive relationship exists, cash flow variables seem to have their strongest effect on R & D during growth periods, implying that anti-recessionary policies, such as lowering corporate income taxes or depreciating write-offs, would also buttress R & D programs against cutbacks.\textsuperscript{21}

4. Firm Size and Inventive Activity

The proper test of the relationship between R & D and the size of the firm is not the absolute amount but the intensity of R & D as a function of size; it is possible to carry out the same volume of research with either a large number of smaller firms or a small number of large firms. It is often stated that large size and monopoly power are complementary attributes, 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 monopoly firms would attract the best innovative talent. It is further argued that some critical size of R & D program is required in order to realize positive returns and that the minimum effort can be undertaken best by large firms. The empirical evidence on the relationship between the size of the firm and R & D effort has been summarized by Kamien and Schwartz, who find that the relationship is at best inconclusive,
mainly due to the vagueness of the definitions of firm size, monopoly power, etc., used in the studies.

In general, 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 concluded that, overall, there is little evidence of anything more than just a proportional relationship between R & D and size. He found that federally-financed R & D is biased towards larger, more diversified firms and that capital-intensive, large-plant companies tend to invest somewhat more in R & D; this could be due to technological and profitability differences among firms in different industries. Holding these differences constant, the evidence for the total sample and for samples of firms in each industry suggested that larger firms invest more, but not relative to their size.

Nadiri and Bitros reach the conclusion that firms, when classified by their asset size, behave in the same manner in acquiring their productive inputs—labor and capital—and their technological input—R & D expenditure. However, there was evidence that substantial cross-sectional and time-series differences in derived demand for R & D, capital, and labor inputs exist among firms in each of the categories of firm asset size. Elliot's results, as well as studies surveyed by Kamien and Schwartz, also confirm the absence of any significant relationship between firm size and R & D expenditure.

In sum, the results confirm previous findings that the relation between the size of firms and their absolute amount of research activity gives no clue as to the industry structure most conducive to R & D—unless it can be shown that research intensity is an increasing function of size.
The evidence for all but the chemical industry seems to disprove the size hypothesis more than confirm it, but there are sufficient weaknesses in the data and methods of estimation to warrant caution. It is true that large average firm size and high concentration are correlated market structure attributes. However, the average firm size and R & D relationship should be distinguished from the R & D and concentration relationship discussed below. The former relates to alleged economies of scale in R & D, while the latter is predicated on the notion that R & D performance is stimulated by the prospect of capturing resultant monopoly gains.

The evidence of a relation between amount of R & D and industry concentration or firm diversification appears to be inconclusive. Grabowski and Mueller, in a recent study using a sample of 150 firms, found that firms do use R & D and advertising to create entry barriers and to raise the rate of return on total capital; they found that the concentration variable had a negative effect on the profit rate—a finding opposite to earlier studies. This is attributed to the high degree of competition through product innovation in concentrated industries. In general, however, previous studies show that the standard hypothesis that R & D activity increases with monopoly power is tenuous; 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 a market structure intermediate between monopoly and perfect competition is most conducive to R & D activity. Thus, to argue 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 is not viable. Policy decisions to promote R & D by increasing
the domination of the large firms in an industry or the degree of concentration of the market cannot be supported from the evidence at hand.

5. The Effect of Regulation

One of the rationales for regulation is that it corrects what economists label a "market failure." 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 insure the proper amount or quality of goods and services at reasonable prices. Thus, the regulatory bodies are assigned the task of regulating the amount and quality of goods and services offered at some specific price. 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 1963-1975. M. Bailey's results show that the level of R & D expenditures necessary to generate a given flow of NCE's is more than doubled as a result of the 1962 amendment. S. Peltzman's study 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. Grabowski, Vernon, and Thomas' comparative study of the introduction of new pharmaceutical products in the U.S. and U.K. shows that, because of the U.S.' stringent regulations, R & D productivity
(measured by the ratio of NCE's to R & D expenditure) declined about sixfold between 1960-61 and 1966-70, while the decrease in the U.K. was about three-fold. They also show that increased regulation has significantly raised R & D costs by roughly twice per NCE in the U.S. 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 U.S. drug firms' investment in manufacturing capacity abroad. Moreover, studies by N. Bailey and D. Schwartzman show that there has been a sharp decline in private rates of return to R & D activity in the post-1962 period; also, Schwartzman's results show a high variability in sales of NCE's since 1962, which is an indication that a significant "risk" premium is appropriate for new drug development throughout the post-amendment period.

Similarly, the study by A. Gellman on innovation in railroads concludes that regulation in railroad and truck transport has slowed down and distorted the pace and pattern on technological change. R. Noll provides similar conclusions in the case of communications networks. MacAvoy and Sloss 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 from a societal point of view and to suggest ways of incorporating
considerations of promoting technological progress as part of the regulatory agencies' decision-making process.

6. **Private and Social Rates of Return**

Most of the recent studies confirm previous findings of high rates of return on R & D. Different studies using different sets of data and methodologies indicate a direct rate of return to R & D of about 25 to 30%, which is more than twice the rate of return on physical capital.\(^{34}\) As mentioned above, Terleckyj's results indicate a 30% direct rate of return and an 80% indirect rate of return for company-financed R & D in manufacturing for the period 1948-1966.\(^{35}\) Griliches calculated these rates for the whole economy to be 20% each in the period 1958-1963.\(^{36}\) Mansfield and his associates estimated private and social rates of return for 17 industries, finding a median private rate of return of 25% and a median social rate of 56%, which suggests a spill-over or externality benefit of about 30%.\(^{37}\)

Not only are rates of return to R & D generally estimated to be very high, partly reflecting the riskiness of R & D programs, but they vary substantially among industries. Terleckyj estimated a zero direct, but large indirect, rate of return for non-manufacturing industries, (in contrast to the 30 and 80%, respectively, for manufacturing). Similarly, Griliches reports gross rates of return of 93% for the Chemicals, Drugs, and Petroleum industry group, and over 20% for Metal, Machinery, Motor Vehicles, and all other industry groups, while for Electrical Equipment and Aircraft and Missiles a low rate of return of 2 to 3% is obtained. The low rates in these two industries are explained as by-products of the depressing effect of the relative specificity of federally-supported R & D in these industries.
Several questions arise in this connection: (i) Why are the returns to R & D so high, even if allowances are made for the likelihood of greater risk? (ii) If these are close to the true rates, why are more resources not allocated to R & D activities in the private sector? (iii) What accounts for the substantial differences in rates of return among various industries? and (iv) What explains the substantial differences between private and social rates of return? The answers to these questions are not obvious and very few studies have adequately addressed them.

On the last question, a recent study by Mansfield and his associates indicates that the social and private rates of return vary greatly for different innovations, the social rate of return exceeds the private rate, and in about 30% of the cases the private rate of return was so low that no firm, with the advantage of hindsight, would have invested in the innovation, while the social rate of return from this innovation 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 process. To be sure, other factors can also be responsible for this gap, but the statistical results of Mansfield's study 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 interesting, but further research must be done before we can fully explain the substantial differences between social and private benefits of R & D.
7. **Composition of R & D and Growth of Productivity**

The distribution of R & D expenditure has been shifting away from basic research towards developmental research, i.e. to the improvement of old and the development of new products and processes. 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. However, there is very little empirical evidence on questions such as: (i) What are the relationships between different types of R & D research, i.e., between basic, applied, and developmental R & D activities? (ii) Can economic considerations explain the shift in composition of R & D expenditure? (iii) What type of time lag relationship exists between each of these types of research and the rate of growth of productivity? (iv) What role does public funding of R & D play in changing the composition?

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 of existing competitors, the size of the existing R & D program, and other industry characteristics. A study by Rasmussen suggests that the anticipated demand for new products and the standard deviation of demand for existing products over a period of six years (as a measure of risk) affect R & D for new product development positively. The more assured the growth of demand for existing products and the greater the profitability of the firm, the less motivation the firm will
have to attempt new product development. However, if the anticipated
demand for the new product is sufficiently strong and the variability of
demand for the existing product is sufficiently high, the greater the
effort to develop new products.

Unfortunately, very little research has been reported on issues
related to compositional change in R & D expenditure (i.e., between basic,
applied, and developmental research) and its relationship to productivity
growth. The implications of a shift in the composition of R & D expenditure
away from basic research (while total R & D expenditure relative to GNP is
declining) for the long-run growth of productivity require close attention
and careful assessment. Similarly we need to know much more about the
process that underlies and the factors that influence the firm's decision
to favor new product development.

8. Problems of Measurement

Most of the studies mentioned above suffer from basic measurement and
specification problems. Some of these problems were pointed out in the
NSF colloquium on the subject in 1972, but, unfortunately, little progress
has been made since then to resolve them. The most important of these
difficulties are, briefly, as follows:

1) The measures of output used in these studies do not allow adjust-
ment for improvement in the quality of goods, which is an important result
of R & D effort. Also, there is a need to reconcile the apparent divergences
of results on the rate of growth of productivity and the contribution of
R & D to this growth obtained from the analysis of a cross-section of
individual firms, on the one hand, and the aggregate or industry time-series
data, on the other. What types of measurement and specification issues are
involved and what can be done to resolve them require close scrutiny.

2) Often the effect of technological progress on other inputs, such as capital, human capital, and stock of knowledge, are not specifically analyzed. The rate of return on other inputs and their depreciation and obsolescence may depend on R & D, but we have little information and few techniques to measure the effects of R & D embodied or not embodied in other inputs. Further, the issue of obsolescence and depreciation of the stock of R & D has not been addressed, let alone measured very well. There is a convention of assigning a 10% depreciation rate to the stock of technology, but this figure is not more than a hunch. Also, the effects of other inputs, such as management information systems, labor training programs within the firm, experience of management, etc., on R & D productivity have been insufficiently analyzed.

3) There is still no satisfactory answer to the question of exactly what is included in measures of R & D for various firms and industries, though some work has begun on this issue. The accuracy of this information is crucial if any credence is to be given to the estimates reported so far and to future studies of the contribution of R & D to productivity growth. The inadequacy of price deflators for R & D in particular industries also prevents any confident comparison of the contributions of R & D by various industries over time.

4) There are some serious specification problems in the models used to estimate the contributions and determinants of R & D effort. Most of the models are fairly simple in structure and do not include all the variables that could affect the relationship between R & D and productivity growth or that could influence R & D spending; the interaction between
R & D and other inputs, for example, affects the contribution of R & D to growth of output. Most of the models are of the equilibrium type and do not explicitly include dynamic features. There is also a simultaneity relation between output and R & D expenditure which is often ignored; the role of relative prices in determining the level of R & D expenditures is also often ignored.

5) Models designed to assess the effects of regulation on innovation have been fairly simple in structure thus far. The effects of regulation on a firm's behavior are likely to be complex and interrelated. Better data and more powerful analytical tools are required to assess the benefits and costs of particular regulatory policies as well as the interrelationships among the policies and their net impact on firm behavior toward technological innovation.

6) More importantly, most of the studies, though published in the 1970's, use data which pertains to the 1960's. Some of the conclusions drawn from these studies may be obsolete by now, especially since both the composition of R & D and the growth of R & D effort has changed in the 1970's. For example, the high rates of return for R & D expenditures found using data for the 1960's (except for the pharmaceutical industry) may not hold for the 1970's; there is a possibility that the decline in R & D expenditure as a percentage of GNP or sales in both public and private sectors is a response to the apparent decline in private and social rates of return. Also, there is some evidence that the traditional sources of comparative advantage for U.S. industries, especially the high levels of R & D intensity in certain industries, have been eroded somewhat in the 1970's. This leads to the conjecture that the R & D-productivity relationship in the U.S.
(especially in some industries) has been undergoing a change in recent years. These conjectures need systematic investigation.

8.1 Assessment of the Results

There has been progress in answering some of the questions raised in the 1972 NSF colloquium. The salient findings can be summarized:

1) There has been confirmation of previous findings of a strong and positive contribution of R & D to growth of productivity and output in various industries, i.e., direct average rates of return (gross) on private R & D expenditure of 30 to 40%. More importantly, the indirect effects of R & D traced through the input-output structure of the economy yield an impressive rate of return. Earlier suggestions that the total rate of return on R & D in the industrial sector was quite high, more than twice as large as that for physical capital, are now fairly well established. However, it should be remembered that these results pertain to the 1960's, since the data for the 1970's have not been adequately analyzed.

2) More attention has been given to the role of publicly-financed R & D, and the results based on firm and industry data seem to suggest that, because of its specificity and its concentration in a few defense-oriented industries, the direct contribution of this type of R & D to growth of output is negligible and its indirect or spill-over effect is not that impressive in comparison with R & D financed from private funds. However, the Chase Econometrics study reports very high rates of return for public expenditure on space-related R & D. The conflict between the micro and macro studies requires systematic analysis. Thus, the presence and extent
of the spill-over of space and military R & D to civilian technology must be accurately measured and thoroughly investigated in order to confirm, modify, or reject the results reported by Chase Econometrics.

3) There is recent evidence that confirms previous results of no economics of scale in R & D; R & D intensity seems to change proportionally with the size of the firm, and there is even some evidence of a diminishing return to R & D as the size of the firm increases. The evidence of a relation between market structure and R & D performance is inconclusive, confirming previous results in this area, and the simultaneity of R & D and market structure has not been fully explored.

4) Some positive evidence has come forth which shows that R & D expenditure responds to changes in relative prices and that existing stocks of capital, labor, and R & D exert important influences on the behavior of R & D and other inputs. Further, there is evidence of strong spill-over effects among the inputs, indicating the presence of strong interdependence among these sources of growth. The sensitivity to relative prices provides a degree of freedom for government to promote R & D effort by providing tax incentives for capital and R & D investments and/or wage subsidies.

8.2 Possible Areas For Future Research

1) An important area for investigation is the possibility of under-investment in R & D in the U.S. economy. Two sets of issues are of crucial importance: (i) Do the high rates of return for R & D in the 1960's still prevail in the 1970's, and, if so, what factors account for them? (ii) If rates of return are still this high, why do not more resources flow to R & D investment? Is there a misallocation in the market, and how could it prevail over such a long period of time?
2) The spill-over effect of publicly-funded R & D, in light of the contradictory results, requires careful analysis; alternative policies to supplement private R & D effort need to be explored. The potential mis-allocation of publicly-financed R & D in the industrial sector need to be re-examined carefully; new areas of needed R & D effort, such as pollution control, housing, urban transportation, energy, and education, may require public funding or strong incentives.

3) The changing composition of R & D expenditure away from basic research and its implications for growth of productivity need to be examined; the substitution and complementarity between various types of publicly- and privately-funded R & D require consideration. Particularly, in order to know how firms adjust their R & D programs, there is a need to incorporate the role of demand and price expectation in the estimation process. Further, there is a need to know the effects of timing, spill-over, and externalities of different types of R & D on growth of output, which requires the development of dynamic models and better data.

4) The effects of government regulation on the rate and timing of innovations in different industries require in-depth analysis. Both the direct effects of government regulations on a particular industry's innovation and then the indirect (spill-over) effects on other industries need to be analyzed and quantified. The over time dynamic impact of such regulations on the structure of various industries, the shift of R & D to other countries, and the competitive position of U.S. industries in world trade should be evaluated.

5) Particular attention should be given to the creative role of government purchasing policies, regulatory agencies' guidelines and practices,
and special federal revenue-sharing in the promotion of innovation. Possible loan insurance programs to encourage R & D innovation in the private sector might be undertaken by the Federal Government. Strengthening basic scientific research at the universities and research institutions should be a primary policy objective of government in order to promote technological progress and reverse the apparent decline in the stock of new knowledge.

6) Another possible area of future research is the relationship between domestic and international developments in technology. The following questions would require examination: Are R & D effort of firms in different countries net substitutes or complements? Does the growth of R & D expenditure abroad (particularly in certain industries) serve to substitute for R & D which is not undertaken in the U.S.? What are the international productivity spill-overs of R & D conducted by U.S. firms? How is the deteriorating position of specific industries in world trade related to their past R & D decisions?

7) Intensive research is needed on the sources and means of promoting innovation in labor-intensive industries, particularly service industries. The consequences of such innovation on the earnings of capital and labor and the displacement costs involved require careful analysis. Also, the spill-over of technological progress in goods industries to service industries and vice-versa should be explored. The transmission mechanism underlying this spreading of technological innovation from goods to service sectors and the degree of complexity of innovations in the two sectors are critical to an evaluation of the effect of total R & D expenditures on the rate of growth of productivity.
8) Finally, and most importantly, there is an urgent need for better data to test the hypotheses suggested on the role of R & D in the growth process. Most existing studies are predicated on disparate sets of economy-wide, industry, or firm data and the results are not comparable; also, most of the studies are out of date. An effort must be made to collect better data, make it accessible, and replicate some of the existing studies. There is also an urgent need to construct dynamic models of innovation and to fully incorporate the R & D decision in the firm's over-all decision-making process.
NOTES

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4. 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, "Research and Development in Industrial Growth," Journal of Political Economy, (March/April, 1971).


6. An average of a somewhat higher elasticity (10%) for research-intensive industries (Chemicals, Metals, and Machinery, Electric Equipment, Motor Vehicles, and Aircraft) and a lower elasticity (4%) for other industries; Zvi Griliches, "Returns to Research and Development Expenditures in the Private Sector," New Developments in Productivity Measurement, National Bureau of Economic Research, (1977, forthcoming), John Kendrick and Beatrice Vaccara, eds.
The distribution of R & D expenditure in each industry to other industries is assumed to be proportional to its sales to them. R & D embodied in intermediate goods purchased by other industries is unevenly distributed, with main concentrations in transportation, communications, utilities, instruments, and construction industries. Capital goods embodying R & D purchased by other industries are more evenly distributed, with highest ratios being in communications, utilities, and air transportation. See Nestor Terleckyj, *Effects of R & D*.


10. Griliches, "Research Expenditure and Growth Accounting."

11. Griliches, "Returns to R & D."


14. Evans, "Economic Impact of NASA R & D Spending."

15. It can be argued that "causality tests" which rely upon the relative strengths of alternative lag specifications, e.g., as used by Ben Branch, "Research and Development Activity and Profitability: A Distributed Lag Analysis," *Journal of Political Economy*, (1974, pp. 999-1011), and W. Leonard, "Research and Development in Industrial Growth," *Journal of Political Economy*, (March/April, 1971, pp. 232-56), are inconclusive because firms may plan to amortize R & D investments over expected future sales volumes.


34. Grabowski and Mueller estimated, using a sample of 180 firms, that the rates of return on physical capital and advertising are equal, about 7% and about 14%, respectively, for R & D. These estimates are quite sensitive to the assumed rates of depreciation and are probably biased downward. See, for further discussion, Grabowski and Mueller, "Rates of Return on Corporate Investment."

35. Terleckyj, "The Effects of R & D on Productivity Growth of Industries."

36. Griliches, "Returns to R & D."

37. Mansfield, et. al., "Social and Private Rate of Return."

38. See, for further discussion of these schema, Serving Social Objectives via Technological Innovation: Possible Near Term Federal Policy Options, National Science Foundation (May, 1973).