ORGANIZATION RESEARCH PROGRAM

# Substitution of Public for Private Research and Development Expenditures

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## ABSTRACT

Government funds used for research and development by industry may have pump priming or substitution effects on the funds that industry itself spends for R and D. Survey data for 1952 and 1960 have been analyzed. The results favor the pump priming hypothesis for the industries that are "traditional" in their funding of R and D, but suggest some substitution in the heavily R and D-oriented industries. There may be a lagged relationship, and there is some evidence of trends which can reasonably be explained by government R and D procurement policies. Differences in the R & D multiplier for different industries may be the result of returns to scale of R & D, structural differences in the industries, or of the relative effects of government programs in creating either product or technological opportunities.

# SUBSTITUTION OF PUBLIC FOR PRIVATE RESEARCH AND DEVELOPMENT EXPENDITURES

Guy Black*

## Introduction

Research and Development by American industry reached $11.5 billion in 1962, resulting in the employment of 329,600 engineers and scientists. Fifty eight per cent of the R & D -- amounting to $6.7 billion--was performed with federal funds, and $4.8 billion with company funds. The growth and the increasing role of government have been dramatic. In 1953, R & D performance was $3.6 billion and only $1.4 billion was federally financed.

Company-funded R & D has, in fact, only kept pace with sales in recent years, being 1.6 per cent of sales in 1957, 1.8 per cent in 1958, 1.7 per cent in 1959 and 1.8 per cent in 1960. There is little evidence of pronounced trends even within particular industries. However, expressed as a per cent of sales, total funds for the performance of R & D by industry have increased steadily from 3.7 per cent in 1957 to 4.3 per cent in 1960.

The fact that total funds for R & D by industry has increased less than proportionately to federal funds suggests the question, have the increased federal funds been used as a substitute for funds that private industry might otherwise have supplied itself? If this is so, it casts doubt on the effectiveness of a policy of federal subsidization of R & D as a possible means of a stimulating economic growth and productivity through broader technological contributions.

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Earlier Findings

The question of substitutability of federal for private R & D funds was raised by Blank and Stigler in 1957.[1] They noted that two-thirds of the increase in expenditures on R & D in the decade to 1950 was governmental, thereby responsible for approximately two-thirds of the increased employment of engineers and scientists. They pointed out that, at one extreme, "it might happen that private businesses first take on government research contracts, as a result of being persuaded of the benefits of research, and then embark on private research also--so that the government contracts serve a sort of pump priming function. At the other extreme, research that businesses had been conducting on their own account might simply be shifted to public contracts, so that these contracts would constitute no net addition."

The authors attempted to explore this question using company reports made available by the Bureau of Labor Statistics, collected in connection with a survey of R & D by industry in 1952. The percentages of technical workers to all employment for firms with and without government research were compared, and it was found that in 12 of 14 industries the percentages in private research was lower for firms with government contracts. A weighted average for all industries gave 0.7 per cent of employment for the firms with government research and 1.4 per cent for those without. The apparent substitution was greatest for firms with under 500 employees and disappeared in firms with over 5000 employees. An important limitation of their analysis is that firms were excluded where engineers and scientists exceeded 10 per cent of total employment: this would eliminate most major defense contractors today.[2]

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[1]David M. Blank and G. J. Stigler, The Demand and Supply of Scientific Personnel (New York: National Bureau of Economic Research, Inc. 1957) pp.57-62.

[2]A recent Bureau of Labor Statistics survey estimates engineers as 21 per cent of employment in military and space electronics manufacturing. See Table 16 of "Employment Outlook and Changing Occupational Structure in Electronics Manufacturing", Bulletin 1363, 1963.

The authors expressed scepticism concerning the crude indication that seven-eighths of professional employment on government research represents a substitution of public for private funds. They suspected--were even confident of--a reporting bias, which they were unable to correct. Thus, if firms that did only government or only private R & D were excluded from the analysis, it would appear as if government funded R & D in an industry was positively correlated with company-funded R & D.

Figure 1 is based on their Table 27, in which ratios of engineers and scientists to total employment are given for companies that do both private and government R & D, in nine industries. On the Y axis is the ratio of engineers and scientists in private R & D to total employment; on the X axis is the figure for the number engaged in government-funded R & D, both performed by industry. The evidence of a relationship is instantly noticeable, as is the fact the regression appropriate for the various industries is different. The petroleum, rubber and textile industries follow a pattern that is best described by a relatively steep regression; the machinery and electrical machinery industries, a flatter one.[3]

These data are certainly promising. The authors estimated that they had obtained coverage of 85 per cent of engineers and scientists in industry. The analysis could be repeated with more recent surveys, which are more complete and probably have improved in technique. In 1960 there were 11,800 firms performing R & D, including 2,115 with R & D budgets in excess of $100 thousand, were covered by National Science Foundation surveys.

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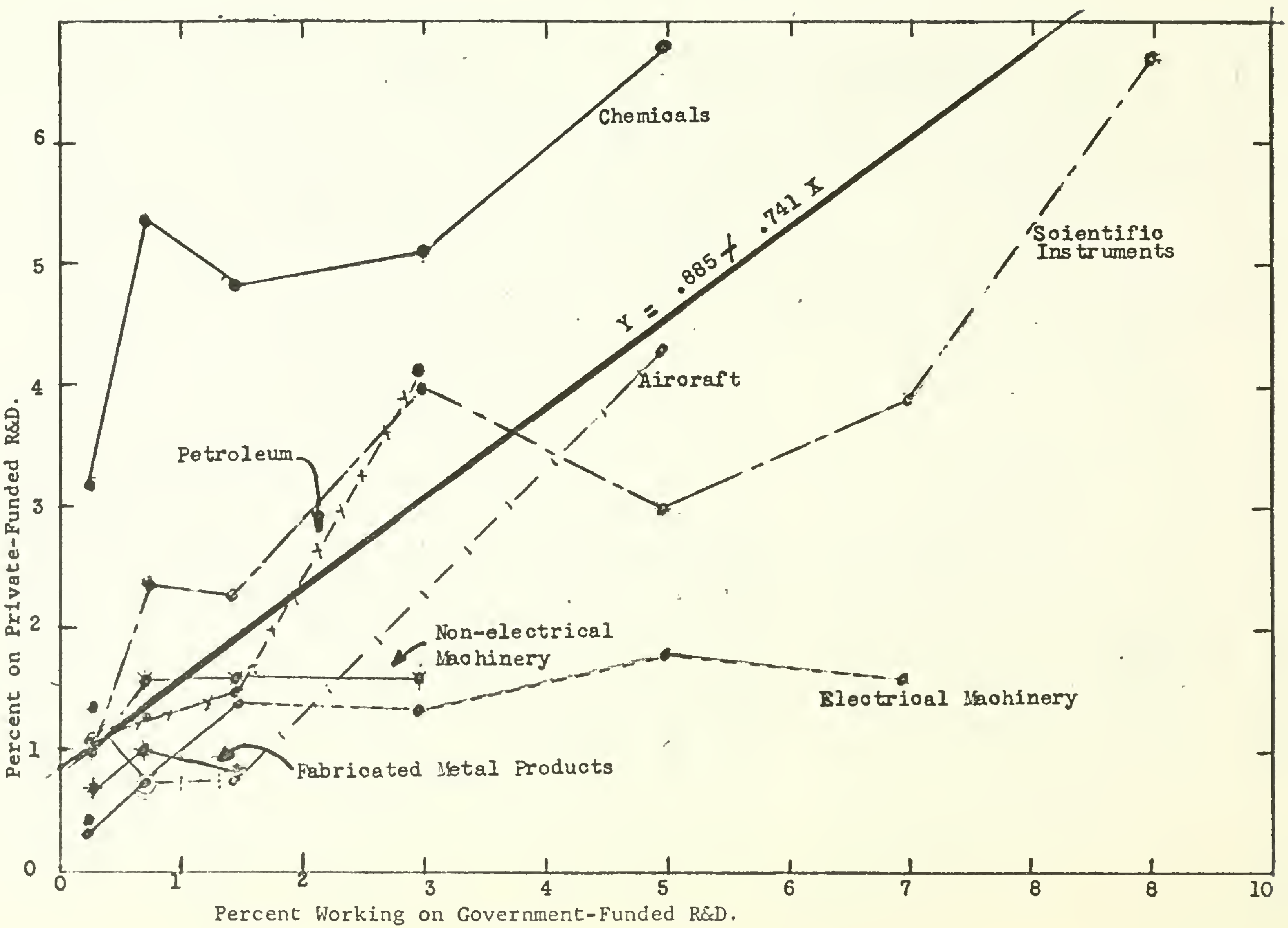
[3] I have fitted a regression to the data which has the form $Y = .885 + 741\ X$ where X is the per cent of employment that is engineers and scientists engaged in government-funded R & D, Y is the per cent of employment that is engineers and scientists engaged in private-funded R & D. The adjusted correlation coefficient is .83. Data for "10.0 or greater" were omitted.

Figure 1

Percentages of Employment that is Engineers and Scientists in Government-Sponsored and Private-Sponsored Research, in Manufacturing Firms Engaged in Both Kinds of Research, by Industry, January 1952




Source of Data: Blank and Stigler, The Demand and Supply of Scientific Personnel, Table 27

## The Pump Priming Hypothesis

At this point, a definition of the term "multiplier" will be useful. A convenient definition is as follows:

$$M_g = \frac{\Delta (R_g + R_p)}{\Delta R_g} = 1 + \frac{\Delta R_p}{\Delta R_g}$$

where $M_g$ is the ratio of the increment in government R & D funds for use in industry ($R_g$) and private funds ($R_p$) combined divided by the increment in government funds alone. The expression implies that related changes only are involved in the definition. Recent trends in R & D funding may be in part the result of other factors, and to estimate $M_g$ directly from available time series is likely to misstate the value.

The multiplier can take a continuous range or positive and negative values. If, for example, government R & D funds do not affect private funds at all, the expression $\frac{\Delta R_p}{\Delta R_g}$ is zero and the value of $M_g$ will be unity. If industry completely substitutes public for private funds, the expression will be minus one, and the value of $M_g$ will be zero; the extreme possibility of negative values of $M_g$ exists in theory, if an increase in government funds results in an even greater decrease in private funds. The condition of pump priming corresponds to values of $M_g$ greater than unity. The usefulness of the definition is that the total R & D funds for use in industry is the product of the multiplier times the increment in government funds. Further, $M_g$ can be obtained from estimates of $\frac{\Delta R_p}{\Delta R_g}$ -- obtained, for example, from a linear regression.

Whether or not government-funded R & D stimulates private R & D would seem to depend on the relative importance of two separate forces. As Schmookler has pointed out, improvement in the state of knowledge improves the prospects for inventions <u>and</u> net profit from R & D: this is one result of government-

funded R & D. Its effect is to increase the visible and profitable product or process opportunities that are achievable through R & D funded by industry.[4]

When opportunities are increased, private industry will be stimulated to undertake the needed R & D. But, the same government-funded R & D that increases visible opportunities would almost certainly be part of the needed R & D, and might in the extreme be the total of it. Where this is so, industry would, in effect, be handed a complete new product or process on which it would not need to spend its own R & D funds. There would be complete substitution of public for private funds: the multiplier would be zero. If, on the other hand, government-funded R & D raised new product or process opportunities more than proportionately to its funding of the needed R & D, private R & D would be stimulated, and the multiplier would be greater than unity. The intermediate case is where there is need for some private R & D, as what was accomplished with government funds reduced the multiplier below unity, although greater than zero. Parenthetically, the creation of visible opportunities in defense markets is particularly closely associated with government-funded R & D; there is little need or opportunity for private-funded R & D directed at defense markets. What is undertaken usually takes the form of demonstrating to government the desirability of advancing R & D funds directed at new weapon development. Here, there is a kind of multiplier operating in a different direction.

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[4]visible opportunities--industry is constantly exploring new product or process opportunities by a combination of technological investigation, product and market studies, cost and profit analyses. The level of private R & D funding depends on how many of the opportunities pass profitability and risk criteria used by management. As a result of R & D activity, the number of technological possibilities is increased, and it stands to reason that a certain portion will pass the critieria. This portion will also be affected by changing patterns of consumer demand, size of market, costs of production, and changes in the criteria. Schmookler points out that the direction of technological advance is not entirely exogenous, being influenced by these considerations.

In this context, it is of interest to review the current interest in the transfer of products or technology from defense-space to civilian purposes. It would appear that the transfer of products <u>or</u> technology would result in quite different values of $M_g$, the R & D multiplier. Substitution is associated with product fallout, and pump priming is associated with the creation of exploitable technology. Where government-funded R & D is devoid of implications for private uses, the multiplier would be unity, as it would be no substitute for private R & D, and would not stimulate any.

This is not the place to develop a full theory as the basis of these remarks. Another part of the story is the competition for the available resources between government-oriented and private-oriented R & D. Account must be taken of government stimulation outside of funding of R & D in industry through such media as the patent system, services to the scientific community, and government laboratories.

Likewise, it seems best to postpone a full consideration of the public policy implications of the multiplier. Product fallout--even without private R & D expenditure--is a public benefit, as is the creation of new technological opportunities. However, a high value of $M_g$ would seem to be a suitable policy objective for government, equivalent to raising the sights for industry but not doing its work; a low value, implying substitution, to be avoided.

## An Interpretation of the Evidence

A pump priming rather than a substitution hypothesis would appear to be supported by Blank and Stigler's data. The slope of the regression indicates that personnel on company-funded projects are associated with those on government-funded at a .74 ratio, corresponding to a multipler of 1.74.

The direction of a causal relationship cannot very well be inferred from these data. It is quite likely that exogenous forces are simultaneously influencing both public and private R & D expenditures. If an attempt is made to use the regression as a predictor, it "overexplains" the increase in private funds relative to government funds, since a regression fitted to 1953-1962 data on federal and private R & D expenditure has a regression coefficient of only .43 (and $\bar{r}_{xy}$ of .89). If there is indeed a causal relationship, it is not well described by a simple regression, or has not been stable over time.[5]

The concepts of pump priming and substitution do appear to consistent with observed business behavior, however.

Pump priming may be found in some industries, some companies, or some R & D but not all. Companies can be and are selective in their participation in federally-funded programs according to the potential for private purposes. Where this potential is great, a relatively large pump priming effect would be expected. The incentive to private industry in a particular program may be a technology that is applicable to other products, a "fallout" product that can be sold in non-government markets, or a pilot study may give the company an advantage in obtaining follow-on production contracts. Recent investigations have lead to the conclusion that new technology rather than new products is the chief benefit to private companies from the missile and space programs. But, to exploit a new technology a company must undertake a product development program. Episodes in which companies have obtained commercially saleable products without private investment, from the performance of government-funded R & D have been disappointingly scarce.[6]

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[5]National Science Foundation, Research and Development in American Industry, 1962, (N.S.F. report 63-37), is the source of the data.

[6]John G. Welles, A.G. Marts, R.H. Waterman, Jr.; J.S. Gilmore and R. Venuti, The Commercial Applications of Missile/Space Technology (Denver: Denver Research Institute, Univer. of Denver, September 1963).

Although these points suggest that pump priming may be the most natural relationship between government-and private-R & D, several contrary inferences can be drawn from the general pattern of industry performance of R & D with government funds. First, recent trends in government procurement favor increasingly specialized programs and products, for which a small multiplier should be expected. In any interindustry comparison, the multiplier should be least where specialization in purely military products is most extreme.

Second, the multiplier should be low in industries in which there are limited opportunities for new products. Thus, a higher multiplier would be expected for food and textile R & D, and a low one for space R & D.

Third, the multiplier should be low in large R & D complexes than in small R & D facilities, for whom an injection of federal funds may be a means of affording an adequate and well-balanced R & D facility.

Fourth, the multiplier should be low in companies that are entirely devoted to government work, and have limited interest in possible private exploitation.

In view of the trends in defense procurement, it would not be surprising if multiplier effects had decreased, especially in the industries that are heavily involved in government R & D. Today, a high percentage of government-funded R & D is done by very large firms that specialize in government work, in industries in which commercial new product opportunities are limited. The incentive to undertake private R & D as a means of winning new weapon contracts has been dulled by the tapering off in new weapon development funds. It is not surprising that only 11 per cent of R & D in the aircraft-missile industry is private.

Recently the Department of Defense has implemented a multistage approach to weapon procurement, one of whose purposes is to reduce the wastage of manpower in extensive competitions for contracts. After competitive proposals are submitted, a limited number of companies are funded for a "program definition" phase; to a degree, this is a deliberate substitution of government for private R & D funds, although much of the "private" funds would come from the public purse indirectly. The effect of such policies should be a further reduction of the multiplier.

Despite these trends, there is some evidence that attempting to achieve a high multiplier is a long-standing governmental policy objective. Despite the manmouth defense R & D budget, many defense and non-defense agencies and projects continue to be severely limited; here especially, administrators husband their funds, strive to get the most R & D for the dollar, and try to encourage private research that will serve their purposes. Token grants to universities or companies are made in an effort to trigger a larger amount of privately funded activity. The multiplicity of small grants by the National Science Foundation are cases in point. In this environment, the multiplier is not so much a stable parameter as a measure of administrative performance. However, there are real bounds to what may be achieved. If missiles are wanted, the money must be spent in the missile industry, even though the pump priming effect may be higher elsewhere.[7]

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[7]Under the independent R & D program defined by Armed Services Procurement Regulation 15, the Department of Defense pays a pro-rata share (usually about two-thirds) of the cost of companies' independently selected R & D programs. The share is negotiated by a multi-service board which judges the relevance of the program to the interests of the Defense Department, and attempts to prevent outright substitution of public for private money. Since the program is a fund-matching one it might be supposed to be purely pump priming, but substitution is certainly possible.

An even simpler causal relationship may operate. Company R & D administrators as well as those in government often prefer a mixture of government and private R & D within the same organization. Funded work can be profitable and can help support a company's laboratory. The ability to win contracts is visible proof to the Board of Directors that the laboratory is competitive in the scientific community; government contracts are often critically important in opening channels of communication on scientific matters. Fairly mechanical rules are often used to determine R & D budgets so that success in obtaining government funds may result in an increase in company funds.

A recent review of the growth of the semiconductor industry said of one period, "it became quite usual in this field, where a considerable amount of government support could readily be obtained, to take a description of the latest development, write it up and present it to the government laboratory as a proposal for funding during the ensuring year".[8] This would seem to be an extreme example of substitutability.

## Evidence from NSF Data

The amount of data available on Research and Development has been greatly expanded in recent years, as a result of the programs of the National Science Foundation. There are now available annual surveys of R & D by industry, going back to 1953.[9]

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[8]Arthur D. Little, Inc., Patterns and Problems of Technical Innovation in American Industry, (Cambridge, Mass.: September 1963), Report C-65344 (reprinted by U.S. Office of Technical Services, No. PB181573), p.172.

[9]National Science Foundation reports are numbered consecutively; the numbers have been used as references.

A few comments on the data are in order. Despite their immense and unique value, their use is complicated by their continual revision. For example, the first estimate of 1959 R & D funds for industry, published in 1960, has been revised repeatedly, and was changed as recently as late 1963.[10] The revisions reflect changing industry definitions, reclassification of particular companies often as a result of acquisitions and mergers (i.e. the acquisition of Philco by Ford), and revisions of data supplied by companies. Data for years prior to 1960--published in 1963--were based on the 1954 S.I.C. classification which was replaced in 1957.

The vulnerability of the data to shifts and reclassifications is enhanced by the concentration of R & D in relatively few firms; the top 40 firms did 68 per cent of all R & D by industry, including 83 per cent of federally funded R & D. A shift of one company between two of the 20-odd industry categories can change data markedly, and care must be taken in constructing time series or cross sectional presentations from a number of N.S.F. sources.

The extent to which reclassification may be a disturbing factor is suggested by a recent comparison of scientific and engineering employment data in private industry on a company basis for 1960, and on an establishment basis for 1961.[11] Shifting to an establishment basis increased the number of engineers and scientists found in food processing by 78 per cent, increased the number

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[10]Thus, N.S.F. 60-81 gives 1959 total R & D funds for industry as $9.438 billion; report 61-51 gives it as $9.553 billion; 62-32 and 63-40 as $9.610 billion; 63-7 and 63-37 give it as $9.609 billion; except that 63-40 identifies the time period as 1959-60.

[11]U.S. Bureau of Labor Statistics, Scientists, Engineers and Technicians in the 1960's -- Requirements and Supply (preliminary) Appendix G.

in electrical equipment by 14 per cent, decreased the number in motor vehicles by 42 per cent and decreased the number in aircraft and parts by 8 per cent. It appears that the practice of assigning entire firms to a single industry may be less satisfactory for the study of research and development than for other purposes.

In order to see what could be learned from time series for particular industries' R & D funding, Table 1 was prepared from the most recently dated sources. Differences in aggregation of data for years earlier than 1957 make the construction of time series a highly dubious proposition; as the footnote references indicate, it was necessary to consult a number of sources to prepare Table 1. Where possible, data has been "disaggregated" so as to narrow the industry definitions. "Other" categories vary considerably in content from year to year, and therefore have not been used.

Table 1 shows the broad participation in the upward trend in R & D activity. Company funds have increased in every industry, and in all but a few there has been an increase in federal funds. Parenthetically, during the five-year period 1957-62 there was a 49.5 percent increase in R & D funds for use by industry--the result of a 55.0 per cent increase in federal funds and a 42.5 per cent increase in private funds. This indicates a marked slowing down in the rate of growth: in the four-year period 1953-57, funds for industry had increased 113.0 per cent, the result of a 203.5 per cent increase in federal funds and a 54.1 per cent increase in private funds.

Pump priming or substitution would seem to depend on patterns of change. To highlight the relationships between changes in the level of funds for R & D

TABLE 1

Federal and Private Funds for R&D By Industry 1957-1962, $ in millions.*

| | 1957 | | 1958 | | 1959 | | 1960 | | 1961 | | 1962 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fed. | Pri. | Fed. | Pri. | Fed. | Pri. | Fed. | Pri. | Fed. | Pri. | Fed. | Pri. |
| All Industry | 4340 | 3390 | 4760 | 3600 | 5640 | 3970 | 6080 | 4330 | 6310 | 4960 | 6729 | 4831 |
| Food | ---- | 67 | ---- | 79 | 5 | 84 | 9 | 94 | 4 | 101 | 5 | 103 |
| Paper | ---- | 45 | ---- | 50 | ---- | 48 | ---- | 53 | ---- | 60 | ---- | 65 |
| Industrial Chemicals | 80 | 423 | 110 | 443 | 114 | 485 | 128 | 538 | 137 | 556 | 158 | 572 |
| Drugs | 0 | 104 | 2 | 126 | 3 | 151 | 4 | 159 | 3 | 177 | 3 | 192 |
| Other Chemicals | 9 | 89 | 14 | 97 | 34 | 105 | 50 | 107 | 83 | 118 | 95 | 130 |
| Petroleum | 16 | 212 | 12 | 229 | 25 | 251 | 26 | 271 | 19 | 275 | 20 | 281 |
| Rubber | 33 | 74 | 23 | 66 | 39 | 72 | 37 | 79 | 36 | 90 | 31 | 94 |
| Primary Metals | 6 | 110 | 13 | 112 | 13 | 123 | 16 | 143 | 16 | 144 | 14 | 152 |
| Fabricated Metals | 45 | 65 | 57 | 64 | 43 | 59 | 38 | 73 | 33 | 86 | 32 | 100 |
| Machinery | 264 | 426 | 316 | 462 | 413 | 511 | 372 | 572 | 292 | 603 | 310 | 633 |
| Communications<br>Other Electrical | 1199 | 576 | 1331 | 616 | 810<br>787 | 284<br>379 | 892<br>725 | 352<br>456 | 784<br>749 | 400<br>472 | 867<br>745 | 413<br>474 |
| Motor Vehicles | 212 | 492 | 318 | 531 | 222 | 622 | 211 | 640 | 192 | 611 | 183 | 675 |
| Aircraft & Missiles | 2266 | 327 | 2276 | 361 | 2769 | 386 | 3180 | 405 | 3537 | 420 | 3787 | 412 |
| Scientific Instruments | 82 | 57 | 92 | 63 | 116 | 64 | 138 | 74 | 109 | 81 | 131 | 87 |
| Optical/Surgical Inst. | 29 | 81 | 40 | 93 | 50 | 104 | 64 | 120 | 67 | 127 | 93 | 144 |

Source of data: National Science Foundation Reports, NSF 60-35; 60-81; 63-7; 63-19; 63-37; 63-40; 63-41.

* "Private" includes company funded R&D performed for account of company by outside organizations on a contract basis.

by industry, Table 2 was prepared. Here, the year-to-year percentage changes in federal and private funds are presented; some observations are not available, but where five data points could be obtained, correlations and regression coefficients were calculated. These do not reveal any strong relationships, except for optical and surgical instruments, and here very consistent parallel trends seem to explain the correlation without generating any confidence in a causal relationship. The natural thought of eliminating trend by a multiple linear regression in which time was an independent variable was rejected because of the paucity of data points (really too few even for simple regressions) and because examination of the data did not seem to justify linear trend assumptions.

A non-parametric test of the relationship between changes in federal and private funds were tried, however. A count was made of the number of times the direction of change in federal funds was the same or the opposite of the change in private funds, in the entire table combined. The possibility of lagged relationships was explored by comparing changes in different years, as indicated by the table headings, in Table 3.

The chi-square test was used to test the null hypothesis that the direction of change in federal and private funds for R & D by industry is unrelated. As can be seen in the table, the null hypothesis can be rejected for fifteen industries combined only where changes in private R & D funds are compared with changes in federal funds two years preceeding. However, the value of chi-square increases regularly from left to right--the lowest values are obtained by comparing changes in private funds in advance of changes in federal funds, and the highest values are obtained by comparing changes in private funds after changes in federal funds. This pattern is consistent with pump priming, and suggests that the relationship is a lagged one.

# TABLE 2

Percent Change in Federal and Private Funds for R&D by Industry, 1957-1962.

| Short Title | Unadjusted Correlation | | 1957 - 1958 | | 1958 - 1959 | | 1959 - 1960 | | 1960 - 1961 | | 1961 - 1962 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fed. | Priv. | Fed. | Priv. | Fed. | Priv. | Fed. | Priv. | Fed. | Priv. |
| | $r_{xy}$ | b | +4 | +8 | +22 | +9 | +8 | +12 | +3 | +4 | +6 | +6 |
| Food | ---- | ---- | ---- | +18 | ---- | +6 | +80 | +12 | -56 | + 7 | +25 | + 2 |
| Paper | ---- | ---- | ---- | +11 | ---- | -4 | --- | +11 | --- | +18 | --- | + 8 |
| Industrial Chemicals | -.36 | -.10 | +37 | + 4 | +3 | +9 | +12 | +11 | + 7 | + 3 | +15 | + 3 |
| Drugs | .50 | 2.81 | ---- | +21 | +50 | +19 | +25 | + 6 | -25 | +11 | 0 | + 8 |
| Other Chemicals | -.02 | -.00 | +56 | +15 | +143 | + 8 | +42 | + 2 | +66 | +10 | +14 | +10 |
| Petroleum | .51 | .02 | -25 | + 8 | 208 | + 9 | + 4 | + 8 | -27 | + 2 | + 5 | + 2 |
| Rubber | .48 | .12 | -30 | -11 | +69 | + 9 | - 5 | +10 | - 3 | +14 | -14 | + 4 |
| Primary Metals | -.25 | -.03 | +116 | + 2 | 0 | +10 | +23 | +16 | 0 | + 1 | -12 | + 5 |
| Fabricated Metals | -.54 | -.26 | +22 | - 2 | -24 | + 8 | -12 | + 6 | -13 | +18 | - 3 | +17 |
| Machinery | .22 | .04 | +20 | + 6 | +31 | +11 | -10 | +12 | -21 | + 5 | + 6 | + 5 |
| Electrical Machinery | -.22 | -.18 | +11 | + 7 | +18 | + 8 | + 1 | +22 | - 6 | + 8 | + 4 | + 2 |
| Motor Vehicles | -.16 | -.04 | +49 | + 8 | -30 | +17 | - 5 | + 3 | - 9 | - 4 | - 4 | +10 |
| Aircraft & Missiles | -.05 | .03 | 0 | +10 | +22 | + 7 | +15 | + 8 | +11 | + 4 | + 7 | - 2 |
| Scientific & Mech. Instr. | -.20 | -.05 | +12 | +10 | +26 | + 1 | +19 | +16 | -21 | + 9 | +19 | + 7 |
| Optical/Surgical Instr. | .90 | .24 | +38 | +15 | +25 | +11 | +28 | +15 | + 4 | + 6 | +38 | +13 |

Source: See Table 1.

TABLE 3

Similarity in Direction of Change of Federal and Private Funds for R&D by Industry 1957-62.

| | Private Before Federal by 2 Years | | | Private Before Federal by 1 Year | | | Same Year | | | Private After Federal by 1 Year | | | Private After Federal by 2 Years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Same | Opp. | Neutral* | Same | Opp. | Neutral | Same | Opp. | Neutral | Same | Opp. | Neutral | Same | Opp. | Neutral |
| Number of Cases | | | | | | | | | | | | | | | |
| 15 Industries | 25 | 15 | 2 | 34 | 18 | 3 | 40 | 23 | 4 | 33 | 17 | 3 | 29 | 8 | 2 |
| 6 High R&D/Sales | 14 | 3 | 1 | 20 | 3 | 1 | 23 | 4 | 2 | 18 | 4 | 1 | 15 | 1 | 1 |
| 9 Low R&D/Sales | 11 | 12 | 1 | 14 | 15 | 2 | 17 | 19 | 2 | 15 | 13 | 2 | 14 | 7 | 1 |
| Chi[2]** | | | | | | | | | | | | | | | |
| 15 Industries | | 1.52 | | | 2.25 | | | 2.52 | | | 3.18 | | | 9.25 | |
| 6 High R&D/Sales | | 5.56 | | | 10.72 | | | 9.96 | | | 7.35 | | | 9.93 | |
| 9 Low R&D/Sales. | | .36 | | | .29 | | | 1.69 | | | 0 | | | 1.64 | |

* Neutral: one of pair no change
** Neutral included with opposite; df=1 for all; .05 level of significance 3.84; .01, 6.64; .001, 10.83.

Source: See Table 2.

Based on a distinction that is discussed in the following section, the comparisons were repeated for a group of six industries in which R & D funding is high relative to sales, and for the remaining nine industries. For the six R & D-oriented industries, the relationship between federal and private funds is high, although there is no good evidence of lagged relationships. For the nine-industry group, there is no evidence of a relationship.

## A Cross Sectional Approach

A cross sectional analysis of the National Science Foundation data was used to approach the question of a relationship in a somewhat different way. Figure 2 presents both federal-and private-funded R & D by industry as percentages of the total sales of companies that perform some R & D.[12]

It is immediately apparent that the industries fall into two groups. The data for six R & D-oriented industries closely fit a negatively sloping regression that is consistent with a substitution effect, although the slope is modest compared to that suggested by Blank and Stigler. The other nine points of industries that may be called "traditional" in their approach to R & D funding, fit a regression is consistent with a pump priming effect. For each group, a regression can be fitted for which the correlation is high.[13] Since the denominator is the same for both government and private R & D as a percent of

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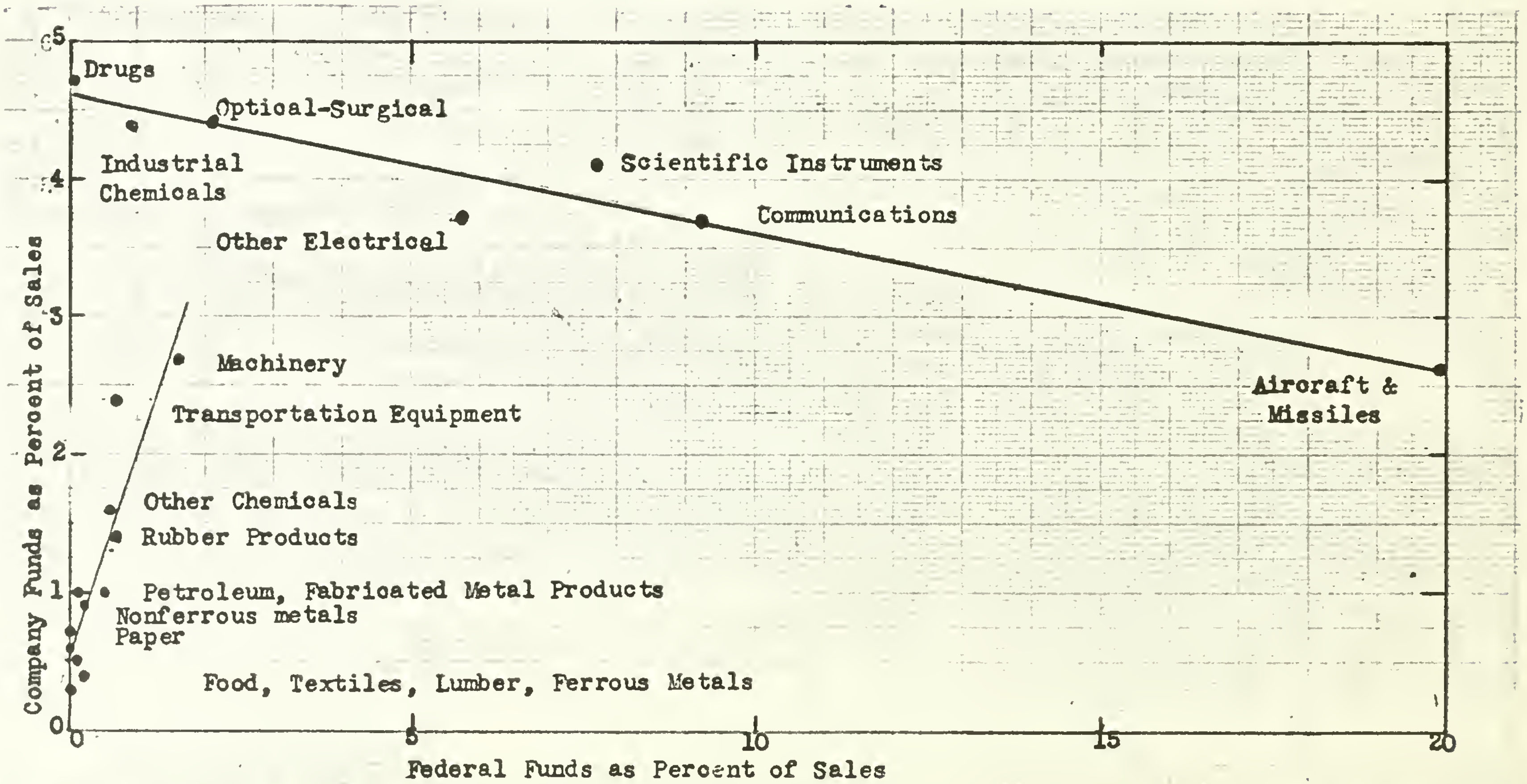
[12]The data are calculated from National Science Foundation, Research and Development in Industry, 1960, Report 63-7, pp. 40-41. Similar calculations for 1957-59 are possible, and yield comparable results but a less clear-cut separation of the two groups.

[13]The expressions are: $X_{cr} = 4.58 - .098\ X_{fr}$ with $\bar{r}$ of .838 and $X_{ct} = .54 + 1.48_{ft}$ with $\bar{r}$ of .890 where $X_{cr}$ is company funds in research-oriented industries; $X_{fr}$ is federal funds in research-oriented industries; $X_{ct}$ is company funds in traditional industries; $X_{ft}$ is federal funds in traditional industries. By "funds" is meant R & D expenditure divided by sales of companies performing R & D.

Figure 2

Company and Government Research and Development as Percentages of Net Sales in Manufacturing Companies Performing R & D, by Industry, 1960



sales, the regression is equivalent to $\Delta I_p / \Delta I_R$ estimated directly from R & D funds, with a correction for size of industry measured by sales.

The significance of these results depends on the rationale of expressing R & D as a percentage of sales. This ratio is, of course, one of those commonly used in financial analysis, and perhaps is most meaningfully compared with profit as a percentage of sales. Here, because private R & D is usually treated as a current expense, a comparison indicates the degree to which current profit taking is being postponed in favor of future profits--that may or may not result from the entrepreneurial venture into R & D.

In an industry where product-oriented R & D is high relative to sales, there is a presumption that the product-line obsolescence rate will be high as a result of that R & D. There is implicit in all R & D activity a shortening of the life of existing production equipment or product lines through obsolescence. The ratio of R & D expense to sales is, therefore, a measure of the level of effort being made to renew the product line of the industry. The efficiency of this effort will naturally vary from industry to industry, and company to company.

The criteria commonly used by industry in approving R & D projects tend to enforce a consistent relationship between the R & D/ Sales ratio and the rate of product line renewal. One commercially oriented electronics manufacturer uses a rule-of-thumb that lifetime sales of a new product must equal at least 15 times the development cost. Interestingly, Ewell has estimated that one dollar of research expenditure has resulted in 25 dollars of additional Gross National Product.[14]

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[14] R. H. Ewell, "Role of Research in Economic Growth" Chemical and Engineering News, Vol.33, No.29, (July 18, 1955), pp.2980-85.

To assume that nearly all R & D by private industry is product-oriented seems to be a reasonable first approximation, that would be appropriate to expressing R & D expenditure as a percentage of sales without a subtraction for process-oriented R & D. Apparently there is little data on the relative importance of product-oriented and process-oriented R & D. One estimate is that of the civilian R & D effort, not more than 15 per cent is spent on R & D for processes against 85 per cent spent for products.[15] The 1962 McGraw-Hill survey of business investment reported that 13 per cent of all manufacturing companies had R & D programs that were primarily oriented toward processes, although the range ran from zero to 42 per cent for some industries. For the special case of government, federally funded R & D, primarily directed at the production of new weapons, amounted to 24.2 per cent of military prime contract awards in fiscal year 1962, which is indicative of the high rate at which new rather than present types of weapons will be added to the arsenal of the future. Since, of course, the product R & D of a capital goods manufacturing industry is directed at process innovation in other industries, process-oriented R & D may be more important nationally than individual industry figures would suggest.

Blank and Stigler expressed the number of engineers and scientists as a per cent of the total number of employees. This measure is related to R & D expenditures as a per cent of sales. Sales per employee and R & D expense per engineer of scientist differ considerably between industries, and with company

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[15]See the remarks of Michael Michaelis in National Security Industrial Association, Proceedings of R & D Symposium, The Impact of Government R & D Expenditures on Industrial Growth, (Washington, 13-14, March 1963), p.175. See also the remarks by W. E. Gustafson, "R & D, New Products, and Productivity Change", American Economic Review LII, (May 1962), pp.178-9.

size. Their "people" ratio will differ for these reasons and will be lower than the "money" ratio because of the higher-than-average wages of the R & D personnel.

It is possible to compare the National Science Foundation data with the Blank and Stigler data by assuming a division of scientific manpower from the division of funds, as only the latter point was covered in the N.S.F. Census survey of R & D by industry. It is commonly suspected that R & D performed for government is more expensive per engineer or scientist than that which companies perform for themselves, but it is not clear from N.S.F. reports that this is so.[16]

In order to develop regressions that were more directly comparable to those of the 1952 data estimates of the numbers of engineers and scientists engaged in federally and privately funded R & D and regressions were calculated. As might be expected, regressions are comparable to those obtained from R & D as a per cent of sales, although the correlation coefficients are much lower.

Thus, we have three sets of regressions obtained from cross sectional comparisons. Blank and Stigler's data, for nine industries in 1952, falls midway between the two sets of regressions developed from National Science Foundation-Census data for 1960, whether on a sales or manpower basis. A comparison of the three sets of regressions and the adjusted correlation coefficients is of interest:

| | 1952 Blank & Stigler Data | National Science Foundation-Census Data | | | |
|---|---|---|---|---|---|
| | | Sales - 1960 | | Manpower - 1960 | |
| | | Research Oriented | Tradition Oriented | Research Oriented | Tradition Oriented |
| Constant term | .885 | 4.58 | .54 | 3.59 | .95 |
| Slope | .741 | -0.098 | 1.48 | -0.196 | 1.12 |
| $R_{xy}$ | .833 | .84 | .89 | .32 | .41 |
| Number of Observations | 37 | 7 | 12 | 7 | 11 |

[16] My evidence on this point is N.S.F. 63-7, pp.87-89.

Implications of the Analyses

How seriously the differences between 1952 and 1960 should be taken as indicative of trends is problematical. There are potentially significant differences in the populations which the data represent. The 1952 data refer only to firms performing both government and private R & D, and firms in which over 10 per cent of the payroll at engineers are excluded; nine industries are covered, and the sample of firms is considerably smaller than for the latter survey. The National Science Foundation-Census survey includes all firms that performed any R & D; nineteen industries are covered, but each industry is a single observation, while the 1952 data was structured by the level of government R & D in each industry, so that there were from two to nine observations for each industry.

A comparison of results from cross sectional analysis with results from analysis of time series yielded an interesting paradox, which can be partially answered. Time series for the R & D-oriented and the traditional industries combined are given in Table 4. They show that there has been an increase in both federal and private funds for R & D in both groups. A regression analysis of the 1957-1962 data yielded these results:

$$X_{ct}=872 + .18X_{ft\cdot} + 70 \text{ (Year-1956)}$$
$$X_{ct}=1305 + .22X_{ft\cdot} + 130 \text{ (Year-1956)}$$

Correlation coefficients for each regression are .99, and standard errors are 39.8 and 28.2 respectively. Thus, in the 6 R & D-oriented industries, company funds have, on the average increased 70/1971=3.5 per cent per year, and in the traditional industries 130/1922=6.8 per cent per year, after statistical account is taken of federal funds. However, in the time series, the increase in private funds has been nearly identical for both industry groups, although federal funds increased at an average of 11.6 per cent per year, and 3.6 per cent respectively.

Table 4

Federal and Private Funds for Research and Development by Industry, 6 R & D Oriented Industries and 9 Traditional Industries, 1957-62

| Industry Group | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | Average % Incr. |
|---|---|---|---|---|---|---|---|
| 6 Research and Development-Oriented | | | | | | | |
| Federal Funds | $ 3,666 | 3,857 | 4,649 | 5,130 | 5,386 | 5,784 | 11.6 |
| Private Funds | 1,613 | 1,702 | 1,857 | 2,104 | 2,233 | 2,294 | 8.5 |
| Percent Federal | 69.5 | 67.5 | 71.2 | 71.0 | 70.5 | 71.6 | -- |
| 9 Traditional | | | | | | | |
| Federal Funds | 585 | 753 | 794 | 759 | 675 | 690 | 3.6 |
| Private Funds | 1,580 | 1,690 | 1,885 | 2,032 | 2,088 | 2,233 | 8.2 |
| Percent Federal | 37.0 | 30.8 | 29.7 | 25.4 | 24.4 | 23.6 | -- |

Source of Data: Table 1

If there is a multiplier effect operative in the traditional industries and a substitution effect in the R & D-oriented industries, it may be the reason for the similar growth rates in the two industry groups. The high growth rate in the federal funds for R & D in research-oriented industries would serve to retard the growth rate in private funds as the multiplier would be about 0.9. The low growth rate in federal funds in the traditional industries where the multiplier would be about 2.5 would retard the growth rate in private funds there.

Both the clustering and the regressions of the 1960 data are intriguing because of the reputation as to progressiveness of the major industries in the R & D-oriented and the tradition-oriented groups. They suggest that the R & D-oriented industries respond to government funding of R & D by slightly reducing private R & D expenditures, but that the traditional industries respond by matching government funds, due to some common causal force or as a result of pump priming. There is some evidence that private funds lag government funds for R & D in the traditional industries. Despite popular views, there is little that is very concrete that may be used to distinguish what have been called R & D-oriented and traditional industries, other than the fact that the heavy involvement of one group in R & D. Table 5 summarizes a few of the statistics that offer some basis for differentiation. For example, it appears that R & D-oriented industries have experienced a markedly higher growth rate, and there has been a greater-than-average increase in total factor productivity, although differences in methods of aggregation fault the comparisons.[17] Distinctions

[17] John W. Kendrick, Productivity Trends in the United States, (footnote con't)

**TABLE 5**

Statistical Characteristics of Industries

| Short Description | Increased Output 1947-58 Percent | Increase in Total Factor Productivity 1948-53 | Full-time Equivalent Engineers and Scientists per 1000 employees 1960 | Funds for R&D Performance by Industry 1960 $ million(e) | Federal Funds for R&D Performance by Industry 1960 $ million | Average No. R&D Engineers & Scientists in Companies with over 5 thousand empl. |
|---|---|---|---|---|---|---|
| Industrial Chem. | 97.6a | 22.5a | 42 | $ 664 | $ 128 | 860 |
| Drugs | | | 43 | 171 | 4 | 340 |
| Communications | 102.8 | 28.1 | 62 | 1,249 | 892 | 1,920 |
| Other Elec. Machy. | | | 42 | 1,184 | 725 | 1,290 |
| A/C & Missiles | 118.8 | 20.3 | 92 | 3,621 | 3,187 | 2,880 |
| Scientific Instr. | 54.3b | 16.2b | 65 | 215 | 138 | 1,280 |
| Optical-Surgical | | | 32 | 184 | 64 | 481 |
| SUBTOTAL | | | | $7,288 | $5,138 | |
| Food | 21.9 | 11.4 | 7 | 104 | 9 | 105 |
| Textiles-Apparel | 4.2-17.1 | 14.4-6.9 | 3 | 32 | 8 | 37 |
| Lumber-Wood | 5.7 | 20.6 | 4 | 13 | 3 | 50 |
| Furniture | 33.2 | 8.8 | | | | |
| Paper | 50.0 | 8.5 | 7 | 54 | -- | 72 |
| Other Chemicals | 97.6a | 22.5a | 29 | 165 | 49 | 290 |
| Petroleum | 38.3d | 16.1d | 13 | 298 | 26 | 376 |
| Rubber Products | 31.4 | 10.7 | 18 | 119 | 37 | 650 |
| Primary Ferrous | 21.4 | 2.7 | 4 | 93 | 2 | 113 |
| Prim. Nonferrous | | | 9 | 69 | 14 | 183 |
| Fabricated Metals | 58.7 | 28.0 | 11 | 112 | 38 | 218 |
| Non-elect. Machy. | 28.6 | 13.6 | 25 | 949 | 372 | 411 |
| Transport exc. A/C | 118.8c | 20.3c | 16 | 852 | 211 | 700 |
| SUBTOTAL | | | | $2,860(e) | $769(f) | |

Sources and footnotes: Kendrick, Productivity Trends, Table D-IV and NSF Publication 63-7, p.51, p.64, p.74 and 86.

a) all chemicals
b) includes miscellaneous
c) all transportation equipment including Aircraft.
d) includes S.I.C. 12 (coal)
e) Total for all industry is $10.546 billion
f) Total for all industry is $6.117 billion

based on organization, markets, or factors of production have not been found. Rates of return, as calculated by Stigler, are not conspicuously different for the R & D-oriented industries, nor are industrial concentration ratios.[18]

There have been efforts to distinguish progressive and traditional industries on a sociological basis. In England, Carter and Williams rated firms on a nine-point scale for 24 characteristics of the technically progressive firm.[19] They found that unprogressiveness was characteristic of long-established industries, usually craft- rather than science-oriented, with old physical plant, low profits, and composed primarily of small firms. This description would not fit some of the industries that I have labelled "traditional" in their funding of R & D, such as primary metals, petroleum, and transportation equipment.

The most substantial basis for distinguishing the two groups is the bare fact that one group is more heavily involved in research and development, which becomes especially evident as the number of comparisons of the two groups is increased. Besides a high ratio of engineers and scientists to all employees and a high ratio of R & D to sales, the research-oriented industries spend the largest part of R & D funds--$7.3 billion of the $10.5 billion of funds for R & D by industry in 1960. They include the industries that are most heavily

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(footnote con't) (Princeton: Princeton Univer. Press, 1961), Kendrick reports a 97.6 per cent increase in total factor productivity for the chemical industries, but increases for the sub-industries identified by N.S.F. are not available. The N.S.F. category "aircraft and missiles" combines S.I.C. 372 and 19 and cannot be compared directly with Kendrick's figure for S.I.C. 37, transportation equipment. Kendrick includes instruments with miscellaneous manufacturing, while N.S.F. breaks S.I.C. 38 into two subgroups.

[18]George J. Stigler, Capital and Rates of Return in Manufacturing Industries, (Princeton: Princeton Univer. Press, 1963).

[19]C.F. Carter and B.R. Williams, Industry and Technical Progress, (London: Oxford Univer. Press, 1957), Ch 16. See also the article by Carter in the March 1959 Journal of Industrial Economics.

dependent on federal funds. They also seem to be the home of the large industrial laboratories, as seen by the numbers in the table 5, the average engineers and scientists per company, in the companies with over 5000 employees.

Diminishing Returns as an Explanation

A possible and perhaps over-simple explanation of a high value of $M_g$ in industries where R & D is low relative to sales, and a low value where R & D is high, is that the return to R & D effort may follow the class "S" shape of production functions, where R & D expenditure is the independent input variable and number or economic value of innovations is the output. With low levels of R & D, firms may be operating in a region of increasing returns, so that any increment of additional R & D funds--federal or private--would raise the marginal return for additional expenditures and would thereby stimulate additional R & D expenditure.

There is some indication that much of the "traditional in approach to R & D" part of American industry is operating in a region of increasing returns in the last column of Table 5. In three of the traditional industries the average number of R & D scientists and engineers in the largest companies in the industry are under one hundred, and in three other the average is under 200. The high figures for the rubber industry and transportation other than aircraft probably result from specialized defense activities (missile fuel and atomic submarines).[20]

That the productivity of a R & D facility fits a pattern of increasing returns when the level of effort is low is implicit in the common view of R & D ad-

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[20]There is very little in the literature about the returns to scale of R & D activity, although there has been some consideration of the return to scale of firm. See Minasian, Op. Cit., p.126.

ministrators that there is a critical size below which a facility is not viable. A commonly mentioned minimum is 20 engineers and scientists, and it is of interest to calculate how large a company that is average in certain respects is likely to be if it is to reach this minimum. Sample calculations for a few industries, based on National Science Foundation figures for 1960, are as follows:

| Industry | R & D costs per Eng-Sci. | Cost of 20- E. & Scitst. | R & D as % Sales | Implicit Minimum Sales for 20 E & S |
|---|---|---|---|---|
| All industry | $26,200 (a) | $524,000 | 2.0 (a) | $ 26.2 million |
| Food, etc. | 21,400 (b) | 428,000 | 0.4 (b) | 107.0 million |
| Electrical Equip. & Communications | 23,100 (c) | 462,000 | 5.9 (c) | 7.8 million |

(a) for companies with total employment of 1000 to 4,999; (b) total employment of 5,000 or more; (c) total employment of under 1000.

These figures suggest that in the traditional industries firms that are very large may still experience pump priming due to increasing returns; that in some of the R & D-oriented industries this factor will more commonly be absent.

The existence of diminishing returns to R & D effort has been speculated on by a number of investigators, who have discovered, for example, that the number of patents per technological worker, per engineer and scientist, or per engineer and scientist engaged in R & D has been declining. The validity of patents as a measure of output has been questioned; if number of publication items per engineer and scientist is used as an output measure, productivity is still rising for industry as a whole.

Conclusions

The evidence presently available suggests that in industries where the level of research and development activity follows the traditional pattern for American industry, an increase in federal research and development funds is associated with an increase in private funds. However, in the industries that are most heavily oriented toward R & D--and receive the bulk of federal funds for R & D--an increase in federal funds seems to be associated with a modest decline in private funds, offsetting somewhat the increase in federal funds. Earlier investigators have suspected the substitution of federal for private funds. My data suggest that this takes place to a far more limited extent than has been suggested. For the industries that follow traditional patterns of R & D support a pump priming hypothesis is more reasonable, and there is some evidence of a lag in the effect. One possible explanation for these relationships is that some industries may be operating in a condition of increasing returns to R & D, so that federal funds serve to increase the marginal return to private investment in R & D. At the same time, the industries which are heavily committed to R & D may be operating under the condition of decreasing returns.

A comparison of 1951 and 1960 statistics suggests that substitution may be an increasing phenomonon in the heavily R & D-oriented industries, but pump priming is increasing in the traditional industries. The first affect would be an expected result of observable trends in government procurement. Defense procurement favors types of R & D and products for which product fallout potential is low. Undoubtedly there are conscious governmental attempts at pump priming, especially in areas which are receiving limited R & D emphasis.

Aside from their pattern of R & D behavior, it is difficult to make a clear distinction between R & D oriented and traditional industries, or to justify the separation of industries into these two groups. There is only limited empirical support for distinctions.