Demand for Engineers and Scientists

By Hugh Folk

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This paper analyzes the demand for engineers and scientists. The supply of engineers and the working of the labor market are treated in other papers (see Folk [1965a, b, c, and d]). This paper includes the following sections:

I. Introduction

II. Growth of R. & D. Spending

III. Secular Growth of Employment

IV. Changes in Engineer and Chemist Ratios

V. Research and Development Scientists and Engineers

VI. Demand for Occupational Specialties

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I. Introduction

It is impossible to define the occupations of engineer or scientist in a manner satisfactory for all purposes. It is therefore impossible to obtain counts of engineers or scientists that are acceptable for all uses. In censuses the respondent defines his occupation and sometimes exaggerates the importance of his job. Some employers exaggerate the qualifications of their work forces. /1 Titles are inexpensive, and if it is necessary to call a technical specialist "junior engineer" or "engineer" rather than "technician" to keep him, many employers will do so. In the United States "engineer" is the standard title for a professional level technical specialist, and does not indicate that the holder has a formal qualification in engineering. Scientific titles, such as "chemist", often attach to jobs requiring only routine and limited technical knowledge and ability that in many countries would be considered technicians' jobs. /2

Criteria of occupational membership such as degrees, society membership, and professional registration are also imperfect in defining occupations. Degrees and society membership probably include as engineers many people that are not doing technical work and exclude many that are. Professional registration is not important enough in most specialties for most employed engineers to bother with.

/1 A partial reconciliation of the 1960 Census estimates of engineer and scientist employment figures with the STP surveys of the Bureau of Labor Statistics for 1960 and 1961 suggests that the census and the surveys are measuring the same population. The proportion of engineers with degrees is much higher in employer surveys than in the Census.

/2 American bachelors degrees in science include much less technical training than British or European first degrees.

While the various definitions contribute to the confusion surrounding the discussion of the "shortage of engineers," I doubt that nomenclature is a very serious problem. In economic terms, defining a particular factor of production means defining a set of perfect substitutes, but no two persons are perfect substitutes since each differs from another in some way. Like employers, we must ignore relatively unimportant differences in order to deal with the problem of production at all. A broad definition of engineers simply includes poorer substitutes than are included in narrower definitions. The problem in engineering is more complex than in, say, dentistry, because licensing by government is of only small importance in engineering. The definition of the occupation used in a particular application in this paper is often dictated by the availability of data. Throughout this analysis of the engineering and scientific labor market I use data from diverse sources. The conclusions drawn from analysis of one set of data will not always apply to all of the labor markets corresponding to the various definitions of engineers and scientists. /1

/1 This study is primarily concerned with engineers, physical scientists, and mathematicians whom I shall term "EPM's" whenever the data or analysis permits. The principle criterion for inclusion in the group is the use of mathematical methods. This group does not include life scientists such as biologists and medical scientists, and I make no analysis of these groups. The life science group is important in universities, but it is not currently very important in industry. In 1961, fewer than 30,000 life scientists were employed in industry (about 4 percent of the total of scientists and engineers). The reason for excluding this group from consideration is that medical research is not very similar to the research and production activities that employ most engineers, physical scientists, and engineers. Consideration of life scientists on the supply side of the market would require the analysis of supply of physicians and some paramedical occupations, and a line must be drawn somewhere. I do not believe there is very much substitution between life scientists and EPM's either in production or in education. It has not always been possible to separate life scientists from other scientists, nor has it been possible to exclude that part of R.&D. spending on medical and biological research.

The demand for engineers is a derived demand, that is, it arises because other goods and services are required by customers and engineers and scientists are useful for production of these final or intermediate goods and services. /1 The demand for engineers and scientists originates largely in manufacturing, government, and education. The demand in manufacturing is both for production and for research and development (R.&D.), while the demand for government is primarily for R.&D. and the demand from education is for R.&D. and teaching. Since the Korean War, the demand for engineers and scientists has been especially closely related to military requirements. The growth of the missile and space programs and the expectation of a long future for the cold war had led to a shift of resources into military R.&D. Engineering employment has grown most rapidly in R.&D. activities while employment in production has grown much less rapidly. During the 1950's the ratio of engineers and scientists to total employment declined in a number of industries. The importance of R.&D. activities, however, should not divert attention from the fact that the majority of all engineers, physical scientists, and mathematicians (EPM's) are employed in activities other than R.&D.

Engineering demand is demand for certain technical skills rather than demand for certain technical people. These skills are usually highly specialized and are often quite unstandardized. The technical skills are either taught in engineering schools or are more easily acquired by persons with engineering training. Engineers are employed because of what they can

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/1 It is for this reason that empirical demand functions for engineering and scientific services cannot be estimated. Estimation would depend on simultaneous estimation of demand and production functions for the goods using engineering and scientific services. Estimates with the statistically essential property of consistency would have to be made witin the framework of an "identifiable" economic structure. For analysis of these econometric problems see a textbook of econometrics such as Johnston [1962].

do or what they can learn. It is obvious, however, that engineering training provides no exclusive license to the learning of these skills. Necessity forces employers to let nongraduates try engineering jobs. These nongraduates may be college graduates without engineering degrees, college dropouts, trained technicians, or simply intelligent workers without college training./1

Confusion between the jobs of engineer and technician is common, and attempts to split technical jobs into two distinct classes labeled "engineering jobs" and "technician jobs" are bound to fail. Employers have little reason to make this distinction when they seek competence in a specific technical skill. Studies both of the aspirations and of the performance of graduates of technical institutes (schools for training technicians) suggest that these institutions should be viewed both as an inferior route to engineering and as a superior route to technicians' jobs.

II. Growth of R. & D. Spending

The postwar surge of organized research and development impelled a rapid growth of the scientific and engineering workforce. Military R.&D. spending provided the major impulse during the 1950's, but space research has grown rapidly since 1961. Private spending grew more slowly; currently it accounts for one-third of the current R.&D. support. Total R.&D. spending has grown at about 13 percent a year and Federal R.&D. spending at 20 percent a year.

/1 Many experts, especially those in professional engineering societies, write as if nongraduates cannot be counted as engineers without doing violence to engineering professionalism. Blank and Stigler [1957] p. 8 assert that "... formal training...is essential" to the definition of engineer. None of the engineering employment estimates we use are rigorous in requiring evidence of training for inclusion, and most make no effort to limit the occupation to persons with formal training. Blank and Stigler also believe that the Ph.D. is a desirable criterion for counting scientists, but this is for economic rather than scientific reasons (p. 12). Machlup [1962], p. 194, goes even further in restrictness: "If we talk about real research scientists, we should look at researchers with a Ph.D. degree." Much of this restrictiveness is simply shoemakers praising shoes, but a fertile field for further research is the analysis of performance and function of "undereducated" scientists and engineers.

This section examines in turn: the trend in total R.&D. spending, spending by source, spending by type of R.&D., and R.&D. performance.

The Trend in Total Research and Development Spending

Everyone agrees that the total amount of research and development has been increasing steadily for years, but there is disagreement about the exact rate of increase. The measurement problems are both definitional and statistical. The definitions in use include in R.&D. a number of scientific and engineering activities that have little or no social utility. These include research directed toward "inventing around a patent" (such as search for compounds that are therapeutically and chemically similar but different enough to be patented), the preparation of proposals for R.&D. contracts (especially for the Department of Defense), and some kinds of technical sales and sales promotion. /1 The statistical problems arise from the limited universe sampled and the freedom firms have to decide how much of their activity is R.&D. The National Science Foundation covers only organized R.&D. and so excludes most individual inventors and much invention in very small firms./2 Nor does the NSF definition include the cost of the large amount of day to day modification and methods improvement made by craftsmen, technicians, and engineers incidental to their primary function in production.

/1 Concern that much activity in R.&D. is not very useful has led to detailed consideration of the problem of efficiency in the conduct of R.&D. See Committee on Utilization of Scientific and Engineering Manpower [1964] and especially Cherington [1964].

/2 This objection has been made by Sanders [1962], p. 59. The exclusion of individual inventive activity is not an important drawback for our analysis, since scientist and engineer employment is concentrated in organized R.&D. rather than individual inventive activity.

Shall we attempt to measure the value of the output of R.&D. or only the cost? This is a familiar problem in national accounting. Since R.&D. output is not usually sold, we cannot easily measure the market value of R.&D. output. This is also true of government services such as police, the courts and defense, and of medical care. The market value of R.&D. projects completed in the year could be estimated by capitalizing the stream of returns resulting from the successful projects. /1 The sum of these values would be the value of R.&D. performed in the year. Much current R.&D. effort is devoted to development of weapons. While some weapons have substantial overseas sales, they are usually priced on a basis of cost plus a fixed profit. Conceivably a military utility index could be constructed which would attribute to R.&D. the increase in military efficiency resulting from an improvement in weapons systems. /2 The problems are considerable, however, and I shall not try to do it here. Measuring the cost of inputs to R.&D. presents enough problems. R.&D. input costs have probably increased faster than average factor costs. The time series of R.&D. performance costs per scientist and engineer in industry increased much less over the period 1957-1963 than did salaries of R.&D. scientists and engineers. /3 I do not think that equipment unit prices

/1 See the studies of Griliches [1958], of Enos [1962], and of Mueller [1962].

/2 This is not only a problem of measuring how big the bang for a buck, but also of rivalry and obsolescence formally similar to fashion goods. A weapon system may be deadly but inefficient because of enemy defensive measures. On a similar value problem, see Scitovsky [1964] on measuring output in medical care. The problem of measuring quality change in a multidimensional product (automobiles) was treated in an important paper by Court [1940].

/3 See Table II-21 below.

and wages of R.&D. workers have increased as rapidly as the salaries of R.&D. scientists and engineers. /1 If so, then equipment and other R.&D. workers have been substituted for scientists and engineers so that the performance cost series have increased much less than the salary series. This means that R.&D. unit costs have probably not increased quite as rapidly as R.&D. salaries. The average quality of R.&D. inputs may have declined, but this is only an impression. With the growth of R.&D. spending, many inferior scientists are supported currently who might not have been supported a few years ago. This is apparently true in universities where the average qualifications of all science and engineering faculty have been declining while university R.&D. spending per scientist and engineer has been increasing. The proportion of all engineers and scientists engaged in R.&D. has been increasing and this is sometimes taken to mean that the quality of the R.&D. work force is decreasing. A large number of these R.&D. scientists and engineers work on large scale projects for which mere competence may suffice.

The attempt to discover a constant dollar cost of R.&D. performance requires a deflator different from the commonly used price indexes of the GNP deflator, the Wholesale Price Index or the Consumer Price Index. Lacking a satisfactory measure of the value of R.&D. output we cannot answer the important question: has R.&D. output increased absolutely and as a percent of GNP? Lacking an adequate deflator we cannot even answer the question: has the constant dollar cost of R.&D. increased absolutely and as a percent of constant dollar GNP?

/1 The only evidence for this is an experimental index of R.&D. costs prepared by the BLS (See Searle [1966] p. 58.) This shows total Army Department R.&D. input costs in 1963 at 106.1 (1961 = 100), and direct labor costs at 107.9 (1961 = 100). In the same year the R.&D. salary index which I use as a deflator stood at 110.2 (1961 = 100). Not all of the Army R.&D. direct labor costs were scientist and engineers' salaries.

For lack of something better we use an index of R.&D. salaries to answer the latter question. [/1] Since R.&D. spending increased as a percent of GNP (both in current dollars and in constant dollars) we conclude that R.&D. spending increased absolutely and as a percentage during the postwar period (Table II-1). The increase in constant dollar R.&D. spending as a percent of constant dollar GNP is much smaller.

The rates of increase of total and government R.&D. spending have been remarkably steady except during wartime (Fig. 1). The rate of increase of total R.&D. spending has been close to 13 percent a year while Federal R.&D. has increased at about 20 percent a year.

Spending by Source

The Federal government is the chief supplier of R.&D. funds. In 1963 about two-thirds of total R.&D. funds came from the Federal government (Table II-2). This percentage has been increasing steadily since World War II (Table II-3). Industry is the next important source of funds. Industry's

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/1 The index used is based on "lifetime earnings" of R.&D. scientists and engineers derived from the Los Alamos survey of R.&D. salaries. The "lifetime earnings" is

$$L = \sum_{t=1}^{R} E_t p_t$$

where E_t is earnings in year t, p_t is the probability of a worker surviving from year 1 through year t. This index is probably biased so that it overestimates the amount of price increase in research and development since salaries have increased faster than most other factor prices. The isolated estimates for 1941, 1943, and 1946 are derived from lifetime earnings for engineers and chemists derived from Bureau of Labor Statistics and American Chemical Society data.

R.&D. spending has decreased as a percentage of total R.&D. spending but has grown more rapidly than gross national product. Colleges and university funds for research have increased rapidly, even though the percentage of total R.&D. spending has decreased.

Federal Government R.&D. Support. The disproportionately rapid growth of Federal R.&D. spending has outpaced private R.&D. spending. This has led to discussions of the "civilian technology gap" or "lag" despite the rapid growth of private spending and total basic research. Most private R.&D. spending is either commercial or purely scientific. The trends in research factor prices suggest that "real" private R.&D. performance has increased both absolutely and as a percent of real GNP (Table II-4).

Federal R.&D. expenditures have grown steadily relative to total government spending from 2 percent in 1945 to 16 percent in 1965 (Table II-5). This represents a trend rate of growth of about 20 percent per year for the last two decades. The increase in R.&D. spending is primarily a result of the cold war. The rate of growth during World War II was rapid, but growth was small in absolute amount. Total war is not a time for experimentation, rather it usually requires substained productive effort, directed toward the output and incremental (or "evolutionary") improvement of proved models. It is in periods of armed truce that modern nations both arm themselves with weapons for today and experiment to discover weapons for tomorrow. The new weapons of World War II--the atom bomb, the V-weapons, and the jet plane--have improved upon by world powers, and these development programs are by their nature expensive. Indeed, the expense of production and the expense of experimentation are both so great that it is a question of high policy

Table II-1

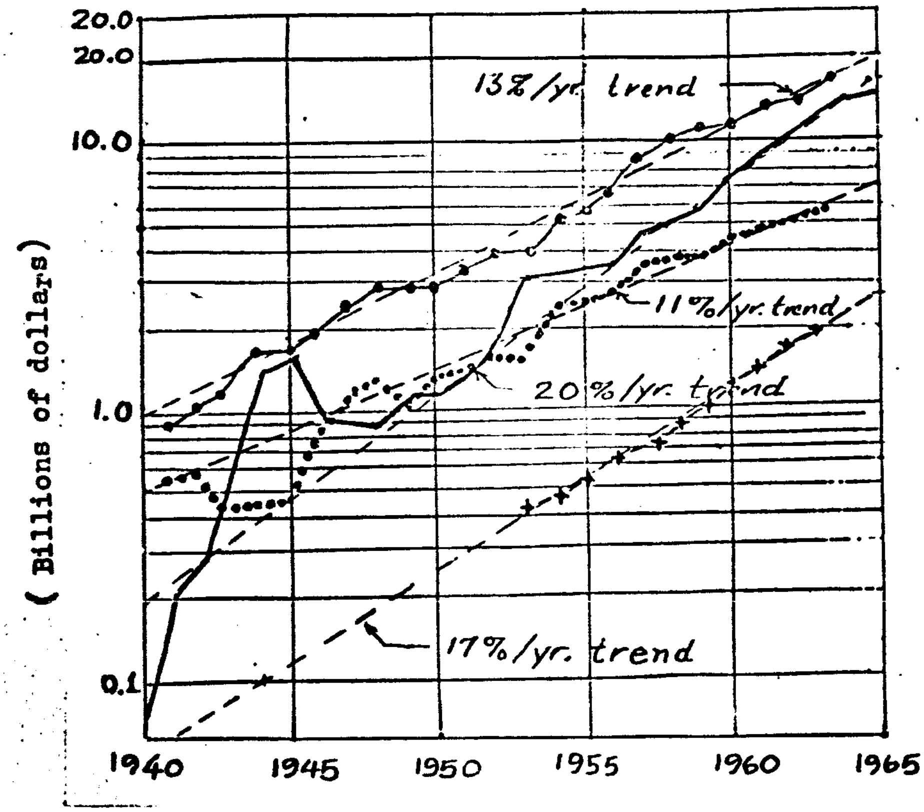
Research and Development Spending in Current and Constant (1958 = 100) Dollars and as Percent of Gross National Product in Current and Constant Dollars, 1940-1963

Year[b]	R.&D. Spending (millions)		GNP (billions)		R.&D. Spending as Percent of GNP	
	Current Dollars	1958 Dollars[a]	Current Dollars	1958 Dollars	Current Dollars	1958 Dollars
1940	$ 900	NA	$ 99.7	$227.2	0.90	NA
1941	1,070	2,629	124.5	263.7	0.86	1.00
1942	1,210	NA	157.9	297.8	0.77	NA
1943	1,380	2,857	191.6	337.2	0.72	0.85
1944	1,520	NA	201.1	361.3	0.72	NA
1945	1,780	NA	212.0	355.4	0.84	NA
1946	2,260	4,124	208.5	312.6	1.08	1.32
1947	2,610	NA	231.3	309.9	1.13	NA
1948	2,610	NA	257.6	323.7	1.01	NA
1949	2,870	4,422	256.5	324.1	1.12	1.36
1950	3,360	5,105	284.8	355.3	1.18	1.41
1951	3,750	5,137	328.4	383.4	1.14	1.34
1952	4,000	5,006	345.5	395.1	1.16	1.27
1953	5,160	6,232	364.6	412.8	1.42	1.51
1954	5,660	7,014	364.8	407.0	1.55	1.72
1955	6,200	7,062	398.0	438.0	1.56	1.61
1956	8,370	9,436	419.2	446.1	2.00	2.11
1957	9,810	10,617	441.1	452.5	2.22	2.34
1958	10,810	10,810	447.3	447.3	2.42	2.42
1959	12,430	11,895	483.6	475.9	2.57	2.50
1960	13,620	12,381	503.8	487.8	2.70	2.54
1961	14,390	12,312	520.1	497.3	2.76	2.48
1962	15,610	12,806	560.3	530.0	2.79	2.42
1963	17,350	13,419	589.2	550.0	2.94	2.45

a. Index based on R.&D. salaries.

b. 1940 to 1952 is 1941 to 1953 in source.

Source: 1940-52 R.&D. spending estimated by Department of Defense.
1953-63 R.&D. spending estimated by the National Science Foundation.



---- Reference trends

—•—•— Total R.& D. spending (13 % / year trend).

——— Federal R.& D. and R.& D. facilities expenditure (20 % / year trend).

•••••••• Private R.& D. spending (11 % / year trend).

—+—+ Basic research spending (17 % / year trend).

Figure 1

Table II-2

Sources of Research and Development Funds, 1953-63[a]

	Millions of Dollars					Percent of Total				
Year	Total	Federal Govern-ment	Indus-try	Colleges and Univers-ities	Other Non-Profit Insti-tutions	Total	Federal Govern-ment	Indus-try	Colleges and Univers-ities	Other Non-Profit Insti-tutions
1953	$ 5,160	$ 2,760	$2,240	$120	$ 40	100	53	43	2	1
1954	5,660	3,120	2,365	130	45	100	55	42	2	1
1955	6,200	3,500	2,510	140	50	100	56	40	2	1
1956	8,370	4,820	3,330	155	65	100	58	40	2	1
1957	9,810	6,105	3,455	180	70	100	62	32	2	1
1958	10,810	6,840	3,700	190	80	100	63	34	2	1
1959	12,430	8,070	4,070	190	100	100	65	33	2	1
1960	13,620	8,770	4,540	200	110	100	64	33	1	1
1961	14,380	9,220	4,810	210	140	100	64	33	1	1
1962[b]	15,610	10,045	5,175	230	160	100	64	33	1	1
1963[b]	17,350	11,340	5,565	260	185	100	65	32	1	1

a. Based on reports of performers and related estimates.

b. Preliminary.

Source: National Science Foundation, "Research Funds Used in the Nation's Scientific Endeavor, 1963," Reviews of Data on Science Resources, No. 7, NSF 65-11, Washington May, 1965, Table 2b, p. 8.

Table II-3

Sources of Funds for Research and Development
Estimated by the Department of Defense, 1941-1958

	Millions of Dollars				Percent of Total			
Year	Total	Govern-ment	Indus-try	Nonprofit institu-tions	Total	Govern-ment	Indus-try	Nonprofit institu-tions
1941	$ 900	$ 370	$ 510	20	100	41	57	2
1942	1,070	490	560	20	100	46	52	2
1943	1,210	780	410	20	100	64	34	2
1944	1,380	940	420	20	100	68	30	2
1945	1,520	1,070	430	20	100	70	28	2
1946	1,780	910	840	30	100	51	47	2
1947	2,260	1,160	1,050	50	100	51	47	2
1948	2,610	1,390	1,150	70	100	53	44	3
1949	2,610	1,550	990	70	100	59	38	3
1950	2,870	1,610	1,180	80	100	56	41	3
1951	3,360	1,980	1,300	80	100	59	39	2
1952	3,750	2,240	1,430	80	100	60	38	2
1953	4,000	2,490	1,430	80	100	62	36	2
1954	4,140	2,460	1,600	80	100	59	39	2
1955	5,400	2,720	2,600	80	100	50	48	1
1956	6,500	3,170	3,250	80	100	49	50	1
1957	8,200	3,750	4,300	150	100	46	52	2
1958	10,230	4,430	5,600	200	100	43	55	2

Source: U.S. Department of Defense, Office of the Secretary, in U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, Washington, U.S. Government Printing Office, 1960, Table 706.

Table II-4

Private Research and Development Spending in Current and Constant (1958 = 100) Dollars and as Percent of Gross National Product in Current and Constant Dollars, 1940-1963

	R.&D. Spending (millions)		GNP (billions)		R.&D. Spending as Percent of GNP	
Year	Current Dollars	1958 Dollars[a]	Current Dollars	1958 Dollars	Current Dollars	1958 Dollars
1940	$ 530	NA	$ 99.7	$227.2	0.53	NA
1941	580	$1,425	124.5	263.7	0.46	0.54
1942	430	NA	157.9	297.8	0.27	NA
1943	440	911	191.6	337.2	0.23	0.27
1944	450	NA	210.1	361.3	0.21	NA
1945	870	NA	212.0	355.4	0.41	NA
1946	1,100	2,007	208.5	312.6	0.53	0.64
1947	1,220	NA	231.3	309.9	0.53	NA
1948	1,060	NA	251.6	323.7	0.41	NA
1949	1,260	1,941	256.5	324.1	0.49	0.60
1950	1,380	2,064	284.8	355.3	0.48	0.58
1951	1,510	2,068	328.4	383.4	0.46	0.54
1952	1,510	1,890	345.5	395.1	0.44	0.48
1953	2,400	2,899	364.6	412.8	0.66	0.70
1954	2,540	3,147	363.1	407.0	0.70	0.77
1955	2,700	3,075	398.0	438.0	0.68	0.70
1956	3,550	4,002	419.2	446.1	0.85	0.90
1957	3,705	4,010	442.8	452.5	0.84	0.89
1958	3,970	3,970	447.3	447.3	0.89	0.89
1959	4,360	4,172	483.6	475.9	0.90	0.88
1960	4,850	4,409	503.8	487.8	0.96	0.90
1961	5,160	4,418	520.1	497.3	0.99	0.89
1962	5,565	4,565	560.2	530.0	0.99	0.86
1963	6,010	4,673	589.2	550.0	1.02	0.85

a. Index based on R.&D. salaries.

Source: 1940-52 R.&D. spending estimated by Department of Defense.
1953-63 R.&D. spending estimated by the National Science Foundation.

Table II-5

Total Federal Expenditures and Expenditures and Obligations for Federal Research and Development, and Research and Development Facilities, Fiscal Years 1940-66

(millions of dollars)

Year	Total Expenditures	Research and Development and Research and Development facilities		R.&D. Expenditures as Percent of Total Federal Expenditures
		Obligations	Expenditures	
1940	$ 9,055	NA	$ 74	0.8
1941	13,255	NA	198	1.5
1942	34,037	NA	280	.8
1943	79,368	NA	602	.8
1944	94,986	NA	1,377	1.4
1945	98,303	NA	1,591	1.6
1946	60,326	NA	918	1.5
1947	38,923	$ 691	900	2.3
1948	32,955	868	855	2.6
1949	39,474	1,105	1,082	2.7
1950	39,544	1,175	1,083	2.7
1951	43,970	1,812	1,301	3.0
1952	65,303	2,194	1,816	2.8
1953	74,120	3,361	3,101	4.2
1954	67,537	3,039	3,148	4.7
1955	64,389	2,745	3,308	5.1
1956	66,224	3,267	3,446	5.2
1957	68,966	4,389	4,462	6.5
1958	71,369	4,905	4,990	7.0
1959	80,342	7,116	5,803	7.2
1960	76,539	8,074	7,738	10.1
1961	81,515	9,601	9,278	11.4
1962	87,787	11,060	10,373	11.8
1963	92,642	13,650	11,988	12.9
1964	97,684	15,310	14,694	15.0
1965(est.)	97,481	16,488	15,371	15.8
1966(est.)	99,687	16,146	15,438	15.5

Source: National Science Foundation, Federal Funds for Research, Development, and Other Scientific Activities, NSF 65-19, Vol. XIV, Table 2.

to decide the proportions in which the military budget is to be split between the needs of the force in being and the hopes of the force of the future. If the military foreground is neglected, then the nation is exposed to insults and provocations that cannot be countered by forces in being. If the military horizon is slighted, the enemy may come up with an innovation that decisively alters the relative strength of the antagonists. Military R.&D. is military investment for the future. /1

Thus it is understandable that during the period since the Korean War American R.&D. efforts have expanded rapidly. The political competition has also spurred rivalry in space, and the substantial American space effort is also classified as R.&D. spending. In a two nation rivalry competitive spending on space which is not directly military has the result of reducing the volume of military R.&D. because it uses resources that might be used for directly military developments.

While military spending has dominated government R.&D., rates of growth of spending by Health, Education, and Welfare (largely medical) and the National Science Foundation have been extremely rapid (Table II-6). By far the most rapidly growing agency in recent years is the National Aeronautics and Space Administration. Part of this growth represents transfer of programs from the Department of Defense to NASA, but it also represents a very substantial making up for the slow growth of DOD since 1961. Without the rapid growth of NASA R.&D. spending or some other increase, the rate of growth of government R.&D. spending would have fallen off.

/1 It is difficult to take the DOD estimates very seriously, but they fill a gap. The DOD estimate for 1953 is $4 billion and the NSF estimate is $5.2 billion. Most of this underestimate is in the industry sector.

Table II-6

Federal Research and Development and Research and Development Facility Expenditures, Selected Agencies, Fiscal Years 1940-6
(millions of dollars)

Fiscal Year	Total	DOD	NASA[a]	AEC	HEW	NSF	Manhattan Project[d]	OSRD
1940	$ 74	$ 26	$ 2	----	$ 3	---	---------	----
1941	198	144	3	----	3	---	---------	$ 5
1942	280	211	5	----	3	---	---------	11
1943	602	395	10	----	3	---	$ 77	52
1944	1,377	448	18	----	3	---	730	87
1945	1,591	513	24	----	3	---	859	114
1946	918	418	24	----	4	---	366	37
1947	900	551	35	$ 38	10	---	186	6
1948	855	592	38	108	23	---	---	----
1949	1,082	695	49	196	28	---	---	----
1950	1,083	652	54	221	40	---	---	----
1951	1,300	823	62	243	53	(c)	---	----
1952	1,816	1,317	67	250	64	$ 1	---	----
1953	3,101	2,455	79	378	65	2	---	----
1954	3,148	2,487	90	383	63	4	---	----
1955	3,308	2,630	74	385	70	9	---	----
1956	3,446	2,639	71	474	86	15	---	----
1957	4,462	3,371	76	657	144	31	---	----
1958	4,990	3,664	89	804	180	33	---	----
1959	5,803	4,183	145	877	253	51	---	----
1960	7,738	5,654	401	986	324	58	---	----
1961	9,278	6,618	742	1,111	374	77	---	----
1962	10,373	6,812	1,251	1,284	512	105	---	----
1963	11,988	6,849	2,540	1,336	632	142	---	----
1964	14,694	7,517	4,171	1,505	793	190	---	----
1965(est)	15,371	7,222	4,900	1,572	813	201	---	----
1966(est)	15,438	6,881	5,100	1,560	964	259	---	----

a. NACA prior to fiscal year 1958.
b. Federal Security Agency before FY 1953.
c. Less than $500,000.
d. Originally War Department (DOD) funds but shown separately to identify funds for atomic energy research.

Source: National Science Foundation, Federal Funds for Research, Development, and Other Scientific Activities, NSF 65-19, Vol. XIV, tables 1 and C-46.

Federal government R. & D. spending is motivated primarily by military needs, but the almost magical faith in scientific research as a cure for all problems has led to rapid growth of research agencies in many government agencies. The government conducts and supports research in many areas of scientific interest or commercial application. This support is also prompted by the government's recognition of the contribution to scientific and technological leadership can make to military, economic, and political leadership. The emergence of the United States as the leading world power has doubtless made Congress more generous in its research support.

Industry Support. Industry support of R. & D. is motivated primarily by search for profits. Industry spends most of its research support for development; nevertheless, it supports about one-fourth of the basic research in the country, about twice as much as is supported by university funds.

Federal support has increased as a percent of total R. & D. spending in 6 of 14 industries over the period 1957-64 (Table II-7). Private spending has not increased at a rate closely related either to the rate of change or relatively importance of Federal financing. This suggests that increased government spending does not have a strong tendency either to increase or to decrease private R. & D. spending when industries are considered as relevant units. /1

Industry private R. & D. spending differs among industries; those that are research oriented, such as chemicals, machinery, and communications spend

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/1 Bland and Stigler [1957] suggest that Federal spending might have a replacement effect on firm R. & D. spending. Black [1964] uses more recent data to show that "pump-priming" rather than "replacement" may be the predominant effect of Federal R. & D. receipts by firms.

Table II-7

Federal and Private Research and Development Funds for Research and Development Performance, by Industry, 1957-64

(millions of dollars)

Industry	1957 Feder-al	1957 Pri-vate	1964 Feder-al	1964 Pri-vate	Federal as % of total 1957	Federal as % of total 1964	Percentage Growth 1957-1964 Total	Percentage Growth 1957-1964 Federal	Percentage Growth 1957-1964 Private
Total	$4,340	$3,390	$7,600	$5,753	56	57	73	75	70
Food	-----	67	-----	-----	0	0	NA	NA	NA
Paper	-----	45	-----	73	0	0	62	NA	62
Industrial chemicals	80	423	172	684	16	20	70	115	62
Drugs	0	104	11	224	0	5	126	NA	115
Other chemicals	9	89	47	146	9	24	97	422	64
Petroleum	16	212	27	310	7	8	48	69	46
Rubber	33	74	26	124	31	17	40	21	68
Primary metals	6	110	8	182	5	4	64	33	65
Fabricated metals	45	65	18	133	41	12	37	-60	105
Machinery	264	426	258	770	38	25	49	- 2	81
Electrical equipment	1,199	576	1,628	1,007	68	62	48	36	75
Motor vehicles[a]	212	492	324	865	30	27	69	53	76
Aircraft and missiles	2,266	327	4,607	489	87	90	96	103	50
Scientific instruments	82	57	120	90	59	57	51	46	58
Optical & Surgical Instruments	29	81	88	185	26	32	148	203	128

a. Includes transportation equipment other than aircraft.

Source: National Science Foundation, "Basic Research, Applied Research, and Development in American Industry, 1964," Reviews of Data on Science Resources, No. 7, NSF 66-6, Washington, 1966, p. 9, table 4.

a relatively large percent of their value added on research /1 (Table II-8). Industrial technical characteristics are obviously important in determining the degree of R. & D. orientation. An industry that spends relatively little on R. & D. may be one whose technology or products are not readily improved by organized R. & D. There is no necessary implication of progressiveness associated with R. & D. spending, but there does seem to be an association between profit rates and research orientation.

Market structure has long been alleged to be related to progressiveness and research support. Oligopoly has been supposed by Schumpeter and others to be associated with innovation and a propensity to spend on research. Schmockler [1959] has argued that there is no correlation of size with R. & D. spending as a proportion of sales, even though the probability of performance is correlated with size. Villard [1959] suggests that this means a concentrated industry will spend more on R. & D. if all firms that perform spend the same percentage since large firms are more likely to perform some research.

University R. & D. Spending. The primary motivation of university spending on research is the traditional role of the university as a contributor to knowledge. In the United States most of the R. & D. spending by universities is devoted to basic research. In 1961-62, for instance, universities spent $230 million on R. & D., of which $180 million was for basic research. Much of this basic research is an outgrowth of the normal process of education. While some universities support research professors, much of these funds was seed

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/1 I have used value added by manufacturing rather than sales or profits as the relevant comparisons because value added is the most precise measure of the amount of economic activity attributable to firms in the industry.

Table II-8

R.&D. Performance and Spending as Percent of Value Added 1962, and Rates of Return on Stockholders Equity, 1963, Selected Industries

Industry	1962 Value Added[a]	1962 R.&D. Spending[b]		R.&D. Spending as Percent of Value Added		Rates of Profit after Taxes on Stockholders' Equity[c] 1963
		Total	Private	Total	Private	
Total manufacturing	179,290	11,560	4,831	6.5	2.7	10.2
Food	20,856	108	103	0.5	0.5	9.0
Lumber and wood	3,606	8	8	0.2	0.2	8.2
Paper and allied	7,044	65	65	0.9	0.9	8.1
Chemicals and allied	16,062	1,151	894	7.2	5.6	12.9
Petroleum	3,439	302	281	8.8	8.2	11.2
Rubber	4,316	126	94	2.9	2.2	9.2
Stone, clay & glass	6,605	117	117	1.8	1.8	8.6
Primary metals	13,744	166	152	1.2	1.1	7.2
Fabricated metals	11,119	132	100	1.2	0.9	8.3
Machinery	16,068	943	633	5.9	3.9	9.6
Electrical equipment	15,595	2,498	887	16.0	5.7	10.0
Transportation equipment	20,946	5,056[d]	1,087[d]	24.0	5.2	15.2
Instruments	4,303	455	231	10.6	5.4	12.0

a. U.S. Department of Commerce, Bureau of the Census, 1962 Annual Survey of Manufactures, reported in Statistical Abstract of the United States, 1964, table no. 1109, p. 773.

b. National Science Foundation, NSF-63-40.

c. Federal Trade Commission and Securities Exchange Commission, Quarterly Financial Report for Manufacturing Corporations, reported in Statistical Abstract of the United States, 1964, table no. 671, p. 497.

d. Includes missiles.

support for graduate student research fellows, and small grants. Nevertheless the college and university spending averaged about $1,800 per science and engineering teacher. /1 Most of this spending was performed by the large endowed private universities and by a few very well supported state universities and by a few very well supported state universities. As a result, university R. & D. spending per full-time equivalent R. & D. engineer or scientist was about $4,000 a year. /2

A considerable part of university R. & D. spending (which may or may not be counted) may be support funds or "seed money" for supported research. University administrators complain that government research contracts do not provide sufficient payment for overhead.

Spending by Type of R. & D.

The National Science Foundation [1963a] defines R. & D. activities as follows:

> Research and development . . . include basic and applied research in the natural sciences, including medical sciences and engineering, and development.
>
> Basic Research . . . [for] three of the sectors, Federal Government, colleges and universities, and other nonprofit institutions..is research in which "...the primary aim of the investigator is a fuller knowledge or understanding of the subject under study, rather than a practical application thereof." ...for the industry sector ... basic research ... [is] "original investigation [s] "original investigation [s] for the advancement of scientific knowledge ... which do not have specific commercial objectives, although they may be in fields of present or potential interest to the reporting company."

/1 There were an estimated 130,000 science and engineering teachers (about one-half of the estimated 269,000 teachers of the rank of instructor or above in the first term of 1961-62 according to Office of Education [1963], Table 55, p. 66.)

/2 Based on an estimate of 52,000 from National Science Foundation [1962] and an estimate of R. & D. spending by colleges and universities of $210 million in academic year 1960-61.

Applied Research ... /for/ colleges and universities"... is directed toward practical application of knowledge." ... /For/ industrial organizations /it/ covers "research projects ... directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes."

Development "... is the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes."

The growth of total R. & D. spending has resulted in a rapid increase in spending on basic research as a percent of total R. & D. spending. Spending on basic research has increased more rapidly than GNP, and has been growing as a proportion of total R. & D. spending. Federal basic research spending has also increased as a proportion of Federal spending and of Federal R. & D. spending (Table II-9). The Federal government provides about three-fifths of all basic research funds, and this proportion is growing (Table II-10). The growing relative importance of the Federal government is understandable because research motivated primarily by the desire to add to the stock of knowledge is not always appropriable or patentable. By the terms of the definition, the expected economic return of any one basic research project is approximately zero. /1 Ordinarily firms in competitive industries will have very little inducement to finance basic research. /2 Firms may support basic research

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/1 Basic research has an analogy in the "pop" record business. The expected profit on any one record by a unknown or little known recording artist is negative. A small percentage of these records make the charts and show profits, and the firm with many records and a good sense of the business will have its share of unpredictable hits. Recording executives are often astonished by the records that become hits. Of course, profits are expected from records by Frank Sinatra or the Rolling Stones, but corporations certainly expect profits from the research of men like Langmuir or Shockley. It is a matter of taste whether a radio studio with its huge pile of rejected and unplayed recordings is a more depressing sight than a journal editor's office with its stack for rejected and unpublishable research reports.

/2 A competitive firm is only a small part of the industry and can only expect to earn the "normal" rate of return on investment. Since we have assumed the expected return of a piece of basic research is zero, it is simply money thrown away for a competitor to perform basic research.

Table II-9

Federal Obligations for Basic and Applied Research and Development, Fiscal Years 1956-63

(millions of dollars)

Fiscal Year	Total R. & D.[a]	Research			Development[b]
		Total	Basic	Applied	
1956	$ 2,990	$ 842	$ 201	$ 641	$2,147
1957	3,924	915	254	661	3,009
1958	4,572	1,034	327	707	3,538
1959	6,692	1,390	484	906	5,302
1960	7,550	1,927	585	1,342	5,623
1961	9,057	2,337	804	1,533	6,702
1962	10,288	2,977	1,085	1,892	7,311
1963	12,464	4,070	1,359	2,711	8,394
1964	14,133	4,541	1,574	2,967	9,592
1965 (estimated)	14,829	5,057	1,808	3,249	9,772
1966 (estimated)	15,280	5,607	2,049	3,558	9,673

a. Excludes obligations for R.&D. facilities.

b. Includes pay and allowances for all military personnel engaged in R.&D. regardless of type work.

Source: National Science Foundation, Federal Funds for Research, Development, and Other Scientific Activities, NSF 65-19, Vol. XIV, tables 3, 6, 10.

Table II-10

Sources of Basic Research Funds 1953-1963[a]

	Millions of Dollars					Percent of Total				
Year	Total	Federal Govern-ment	Indus-try	Colleges and Univers-ities	Other Nonprofit Insti-tutions	Total	Federal Govern-ment	Indus-try	Colleges and Univers-ities	Other Nonprofit Insti-tutions
1953	$ 412	$ 184	$146	$ 57	$ 25	100	45	35	14	6
1954	455	NA	NA	62	31	100	NA	NA	14	7
1955	517	NA	NA	70	38	100	NA	NA	14	7
1956	619	NA	NA	75	41	100	NA	NA	12	7
1957	721	334	247	90	50	100	46	34	12	7
1958	882	443	272	111	56	100	50	31	13	6
1959	992	537	272	118	65	100	54	27	12	7
1960	1,135	593	325	140	77	100	52	27	12	7
1961	1,324	713	348	161	102	100	54	26	12	8
1962[b]	1,575	910	367	180	118	100	58	23	11	7
1963[b]	1,815	1,060	400	220	135	100	58	22	12	7

NA = not available

a. Based on reports by performers and on related estimates.
b. Preliminary.

Source: National Science Foundation, "Research Funds Used in the Nation's Scientific Endeavor, 1963," Reviews of Data on Science Resources, NSF 65-11, Washington, May 1965 table 3b, p. 8.

because they are so concentrated in a field of technology and the technology is so concentrated in the firm that basic advances will bring returns. Thus DuPont may expect to benefit from almost any advance in chemistry even though they cannot see precisely how it will happen. In a very real sense, "What is good for chemistry is good for DuPont." Nylon is the classical example of a successful commercial application from basic reasearch. /1 Oligopolistic interdependence and market practices may be important in influencing basic research spending by industry even if it is not very important in influencing spending on development and applied research.

In ordinary circumstances basic research performance for mutual benefit by industry depends on a kind of tacit mutual agreement. Such tacit collusion serves the same purpose as a industry sponsored research agency, and might be expected to settle on a percentage of sales as the appropriate parameter. The practices of cross-licensing (as in chemicals) or patent pool (as in automobiles) result partly from recognition of the mutual advantages of research.

Spending for applied research and for development is economically motivated. The work is performed because it is "practical" or "useful." This does not necessarily mean that executive committees or research directors consciously estimate expected economic return on individual projects of their company financed R. & D. (Government financed R. & D. is a product to the company while their own is an investment undertaken for the objective of profit). It only means that the responsible corporate officials believe the projects are either directly or indirectly profitable.

/1 For a discussion see Mueller [1962], pp. 334-37.

Performance of R. & D.

Almost four-fifths of R. & D. is performed by industry (Table II-11 & 12). This performance is financed almost equally by the Federal government and by industry itself (Table II-13). The second largest performer of R. & D., the Federal government, is wholly self financed. Colleges and universities (principally universities) are the next largest group of performers, drawing a majority of their funds from the Federal government. From 1953 to 1963 R. & D. performance by the Federal government increased about two-and-one-half times, industry performance increased about three-and-one-half times, university performance increased four times, and nonprofit institutions increased more than five times.

The elements of the flow of R. & D. funds matrix have changed steadily with the Federal government becoming more important as a source of funds and less important as a performer and industry becoming less important as a source of funds and more important as a user or performer (Table II-13 and II-14).

Industry Performance. The rapid growth of Federal government R. & D. spending and its concentration in a few industries such as aircraft and parts and electronics has led to the emergence of large firms that specialize in military R. & D. and production. Examples of large firms are chiefly in aircraft, but there are many smaller firms in electronics. Many American corporate giants have large defense divisions. In fiscal year 1962, seven of the largest ten military contractors were in aircraft and missiles. These seven accounted for about $2.6 billion or 62 percent of the $4.2 billion of R. & D. performed in the aircraft and parts industry in 1962, or 22 percent of the $11.6 billion total industry performance. This $2.6 billion is also

Table II-11

Performance of Research and Development, 1953-63[a]

	Millions of Dollars					Percent of Total				
Year	Total	Federal Govern-ment	Indus-try	Colleges and Univers-ities	Other Non-profit Insti-tutions	Total	Federal Govern-ment	Indus-try	Colleges and Univers-ities	Other Non-profit Insti-tutions
1953	$ 5,160	$1,010	$ 3,630	$ 420[b]	$100	100	20	70	8	2
1954	5,660	1,020	4,070[b]	450	120[b]	100	18	72	8	2
1955	6,200	950[b]	4,640[b]	480[b]	130[b]	100	15	75	6	2
1956	8,370	1,090	6,610	530[b]	140[b]	100	13	79	6	2
1957	9,810	1,280	7,730	650[b]	150	100	13	79	6	2
1958	10,810	1,440	8,390	780	200[b]	100	13	77	7	2
1959	12,430	1,730	9,620	840[b]	240[b]	100	14	77	7	2
1960	13,620	1,830	10,510	1,000[b]	280[b]	100	13	77	7	2
1961	14,380	1,890	10,910	1,200[b]	380[b]	100	13	76	8	3
1962[c]	15,610	2,220	11,540	1,400[b]	450[b]	100	14	74	9	3
1963[c]	17,350	2,400	12,720	1,700[b]	530[b]	100	14	73	10	3

a. Based on reports by performers.
b. Estimated by the National Science Foundation. No sector survey in year.
c. Preliminary.

Source: National Science Foundation, "Research Funds Used in the Nation's Scientific Endeavor, 1963," Reviews of Data on Science Resources, No. 7, NSF 65-11, Washington, May, 1965, table 2a, p. 6.

Table II-12

Performance of Research and Development, Estimated by the Department of Defense, 1941-1958

	Millions of Dollars				Percent of Total			
Year	Total	Govern- ment	Indus- try	Nonprofit institu- tions	Total	Govern- ment	Indus- try	Nonprofit institu- tions
1941	$ 900	$ 200	$ 660	$ 40	100	22	73	5
1942	1,070	240	780	50	100	22	73	5
1943	1,210	300	850	60	.100	25	70	5
1944	1,380	390	910	80	100	28	66	6
1945	1,520	430	990	100	100	28	65	7
1946	1,780	470	1,190	120	100	26	67	7
1947	2,260	520	1,570	170	100	23	69	8
1948	2,610	570	1,820	220	100	22	70	8
1949	2,610	550	1,790	270	100	21	69	10
1950	2,870	570	1,980	320	100	20	69	11
1951	3,360	700	2,300	360	100	21	68	11
1952	3,750	800	2,530	420	100	21	67	11
1953	4,000	770	2,810	420	100	19	70	11
1954	4,140	700	3,020	420	100	17	73	10
1955	5,400	1,000	3,950	450	100	19	73	8
1956	6,500	1,110	4,920	470	100	17	76	7
1957	8,200	1,370	6,280	550	100	17	77	7
1958	10,230	1,380	8,100	750	100	13	79	7

Source: U. S. Department of Defense, Office of the Secretary, in U. S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 1960, Washington, U.S. Government Printing Office, 1960, table 706

Table II-13

Percentage Distribution of R.& D. Funds by Source and Use, 1963

	Uses						
					Colleges and universities		
Sources	Total	Federal	Industry	Other nonprofit institutions	Proper	Federal contract research centers	Total millions
Total	100.0	13.8	73.3	3.0	6.8	3.0	$17,350
Federal	65.4	13.8	42.3	1.7	4.5	3.0	11,340
Industry	32.1	--	31.0	0.7	0.4		5,565
Other nonprofit institutions	1.1	--	--	0.6	0.4		185
Colleges and universities	1.5	--	--	--	1.5		260
Total (millions)	$17,350	2,400	12,720	530	1,175 1,700	525	

Source: National Science Foundation, "Research Funds Used in the Nation's Scientific Endeavor, 1963," <u>Reviews of Data on Science Resources</u>, Vol. I, No. 4, NSF 65-11, May, 1965, table 4, p. 8.

Table II-14

Percentage Distribution of R. & D. Funds by Source and Use, 1953

	Uses					
Sources	Total	Federal	Industry	Other nonprofit institutions	Colleges and universities	Total (millions)
Total	100.0	19.6	70.3	1.9	8.1	$5,160
Federal	53.5	19.6	27.7	1.2	5.0	2,760
Industry	43.4	--	42.6	0.4	0.4	2,240
Other nonprofit institutions	0.8	--	--	0.4	0.4	40
Colleges and universities	2.3	--	--	--	2.3	120
Total (millions)	$ 5,160	1,010	3,630	100	420	

Source: National Science Foundation, "Research Funds Used in the Nation's Scientific Endeavor, 1963," Reviews of Data on Science Resources, Vol. I, No. 4, NSF 65-11, May, 1965, table 4, p. 8.

37 percent of the \$9.6 billion total of Federal government R. & D. spending, and 69 percent of the \$3.8 billion of Federal R. & D. spending in the aircraft industry. /1

The share of aircraft industry in total R. & D. performance stood at 36 percent in 1961, a light increase from 33 percent in 1956. Of this, \$3.5 billion or 89 percent was Federal money in 1961. Of the total only one percent was for basic research.

The largest industrial performer of privately financed R. & D. is the chemical industry. Industrial chemcials is the largest performer of the constituent minor industries and it has substantial government support.

Industrial R. & D. performance by non-manufacturing firms amounts to less than 10 percent of total R. & D. spending. This demonstrates the predominance of development of large weapons systems.

Basic research is not so closely tied to hardware production as is development and universities play a major role in the conduct of basic research (Table II-15). Industry has become relatively less important as a performer of basic research, while the Federal government and nonprofit institutions have become more important.

University Performance. Colleges and universities perform a substantial part of Federal government research, especially basic research. Research performance is highly concentrated in universities rather than colleges, and among the universities it is highly concentrated in the few institutions of world reputation that emphasize graduate study. Several of these, such as the University of California, the University of Chicago, the Massachusetts Institute of Technology, and the California Institute of Technology administer

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/1 See National Science Foundation [1963b].

Table II-15

Performance of Basic Research, 1953-1963

Year	Millions of dollars: Total	Federal government	Industry	Colleges and universities	Other nonprofit institutions	Percent of total: Total	Federal government	Industry	Colleges and universities	Other nonprofit institutions
1953	$ 412	$ 45	$ 151	$ 190[b]	$ 26	100	11	37	46[b]	6
1954	455	47	166[b]	208	34[b]	100	10	36[b]	46	7[b]
1955	517	55	189[b]	230	43[b]	100	11	37[b]	40	8[b]
1956	619	65	253	250[b]	51[b]	100	11	41	40[b]	8[b]
1957	721	90	271	300[b]	60	100	12	38	42[b]	8
1958	882	115	305	392	70[b]	100	13	35	44	8[b]
1959	992	155	332	420[b]	85[b]	100	16	33	42[b]	9[b]
1960	1,135	147	388	500[b]	100[b]	100	13	34	44[b]	9[b]
1961	1,324	190	407	575[b]	152[b]	100	14	31	43[b]	11[b]
1962[c]	1,575	229	471	695[b]	180[b]	100	15	30	44	11
1963[c]	1,815	275	500	840[b]	200[b]	100	15	28	46	11

NA = not available

a. Based on reports of performers.

b. Estimated by the National Science Foundation. No sector survey in year.

c. Preliminary.

Source: National Science Foundation, "Research Funds Used in the Nation's Scientific Endeavor, 1963," Reviews of Data on Science Resources, NSF 65-11, May, 1963, table 3a, p. 7.

large government owned laboratories (Federal contract research centers) with huge budgets. Cooperatively managed facilities such as Brookhaven National Laboratory are important. These operations are not integrated into the university's educational programs.

A very large part of the research within universities is conducted by regular faculty members, sometimes organized in specialized centers or institutes. Supported research allows universities to support larger faculties and to cover more scientific specialties. Many regular faculty members receive summer pay and released time during the year to conduct supported research. Government support has allowed the universities of established reputation to expand their facilities, faculties, and graduate student support and has thereby contributed to the expansion of the supply of engineers and scientists. Nevertheless, university performance of supported research has been criticized. Many people believe that government research support has led to imbalance by expanding the sciences and ignoring the humanities. /1 Others believe that too much university effort has been diverted in R. & D. activities that are only tangentially related to higher education. Among these critics are commercial research companies who find in universities and individual professors subsidized competition. Still other critics believe the Federal research support has contributed to an unhealthy deemphasis of undergraduate education.

III. Secular Growth of Employment

The number of engineers and scientists increased from 702,700 in 1950 to 1,157,300 in 1960, and this represented an average annual rate of growth of 5.1 percent a year. This growth occurred during a period of almost revolutionary

/1 See Orlans /1962/ for a survey of faculty opinions and discussion of this point.

changes in employment patterns of scientists and engineers. Research and development employment of scientists and engineers grew from 151,000 in 1950 to 387,000 in 1960, and this was an average annual rate of growth of 9.9 percent a year. The proportion of all scientists and engineers employed in R. & D. increased from one-fifth in 1950 to one-third in 1960. Much of this growth occurred as a result of military R. & D. spending. Most of the recent increase in space research came after 1960. Even so, one-fifth of all engineers and scientists were in the electrical and aircraft industries in 1960, and the proportion has since increased.

This section and the next deal with employment of engineers and chemists in order to continue the extensive analysis of Blank and Stigler [1957]. Little is lost by this limitation, and no violence is done by the omission of scientists who are not chemists from our analysis except in the instance of universities and colleges. About 90 percent of scientists and engineers in private industry are either chemists or engineers. Most of the excluded scientists are university or college instructors and this occupation is analyzed in another paper.

Why has the number of engineers and chemists grown from about 52,000 in 1900 to 941,000 in 1960? Engineers and chemists increased much more rapidly than the labor force. The ratio of engineers and chemists to total employment (E. & C. ratio) increased from 0.18 percent in 1900 to 1.46 percent in 1960. I am primarily interested in the period since 1940, and fortunately the analysis of Blank and Stigler adequately covers the period before 1950. /1 They find that before 1940 the change in industry composition accounts for about one-half

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/1 This and the following section owes a great debt to Blank and Stigler [1957] pp. 47-72. Much of my analysis is an updating of their work.

of the change in the national E. & C. ratio, while changes in the industry E. & C. ratios account for the other half. /1 They conclude that the increase in industry E. & C. ratios is the result of : (1) decreasing relative cost of engineers and chemists; (2) changing industrial technology which requires different proportions of technical manpower in different industries; and (3) the growth after 1940 of the E. & C. ratios associated with R. & D. performance.

The pattern of change in industry E. & C. ratios is analyzed in detail in the next section: here I examine the effects of changes in industrial composition on the national E. & C. ratio since 1940. Letting E_t be total employment in year t, E_t^i be employment in industry i in year t, and C_t be employment of engineers and chemists in year t and C_t^i be employment of engineers and chemists in industry i in year t, we will have the total change in the national E. & C. ratio as

$$\left(\frac{C_{50}}{E_{50}} - \frac{C_{40}}{E_{40}} \right) = D_{50} \tag{1}$$

and following Blank and Stigler we obtain the change in the ratio attributable to change in industry composition assuming industry E. & C. are constant at their 1940 levels as

$$D_{50}^{c} = \frac{C_{50}}{E_{50}} - \sum \left(\frac{E_{50}^{i}}{E_{50}} \cdot \frac{C_{40}^{i}}{E_{40}^{i}} \right) \tag{2}$$

/1 The E. & C. ratio increased from 0.18 in 1900 to 0.68 in 1940, or 0.50 percentage points. If industry E. & C. ratios had been constant at the average of their 1930, 1940, and 1950 values, the total E. & C. ratio would have been increased from 0.48 to 0.76, or 0.28 percentage points, thus change in industry composition accounts for 0.28/0.50, or 56 percent of the change in the total E. & C. ratio.

Hence, the proportion of the total change D_{50} attributable to change in industry composition is simply D^c_{50}/D_{50}. /1 We compute the total effect of change in industry composition, and also identify the principle contributors, which are industries that grew as a proportion of total employment and also had large 1940 E. & C. ratios. A rapidly growing industry had little effect if it had a small E. & C. ratio.

The analysis for 1940 to 1950 shows that industry composition accounts for about 40 percent (or 0.16 percentage points) of the 0.40 percentage point change in the national E. & C. ratio from 1940 to 1950. There was an increase of about 162,000 engineers and chemists attributable to changes in industry employment. The most important industries were construction, electrical equipment, and the Federal government, which increased by 26,000, 19,000, and 37,000 respectively, assuming 1940 E. & C. ratios remained constant. These three industries account for about one-half of the increase in the number of engineers and chemists attributable to changes in industry composition. The E. & C. ratio would have been 0.82 if the 1940 industry E. & C. ratios had not changed, but the actual national E. & C. ratio was 1.06, showing that 0.24 percentage points attributable to increases in industry E. & C. ratios. Of this change 0.05 percentage point is attributable to the increase in the Federal government E. & C. ratio, and 0.02 percentage points each to construction, aircraft, drugs and miscellaneous

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/1 It is possible to measure the effect of change in industry ratios directly by computing D^r_{50} as follows:

$$D^r_{50} = \frac{C_{50}}{E_{50}} - \sum \left(\frac{C^i_{50}}{E^i_{50}} - \frac{C^i_{40}}{E^i_{40}} \right) \frac{E^i_{40}}{E_{40}}$$

This will differ from $1 - D^c_{50}/D_{50}$ because $\sum \left(\frac{C^i_{50}}{E^i_{50}} - \frac{C^i_{40}}{E^i_{40}} \right) \left(\frac{E^i_{50}}{E_{50}} - \frac{E^i_{40}}{E_{40}} \right)$ (the interaction term) is not generally equal to zero.

chemcials combined, and communications. These five industries account for about one-half of the increase in the national E. & C. ratio attributable to increases in industry ratios.

A similar analysis for the period 1950-1960 assuming 1950 industry E. & C. ratios remain unchanged shows that the change in industry composition of total employment accounts for 36 percent of the change in the national E. & C. ratio from 1.06 in 1950 to 1.46 in 1960. There was an increase of 185,000 engineers attributable to the increases in industry employment, and the increases of the most important industries electrical equipment--35,000, aircraft--36,000, professional services--24,000, and nonferrous metals--17,000. These four industries accounted for 102,000 or 55 percent of the increase in employment attributable to changes in composition. Of the 0.25 percentage points of the increase in the national E. & C. ratio attributable to the increase in industry E. & C. ratios, about three-fifths, or 0.15 percentage point, was accounted for by increases in the E. & C. ratios of electrical equipment, aircraft, professional equipment, office machinery, and nonferrous metals. About 0.05 percentage point was accounted for by the increase in the ratio of electrical equipment alone.

The foregoing analysis shows that much less than half of the increases in the national E. & C. ratio from 1940 to 1950 and from 1950 to 1960 arises from differential industry growth, while most of the change in the national E. & C. ratio for the two decades is attributable to changes in the E. & C. ratios of a few industries.

IV. Changes in Engineer and Chemist Ratios

It was shown in the preceding section that changes in the industry ratios of engineers and chemists to total employment (E. & C. ratios) accounted for a major part of the increase in the national E. & C. ratio from 1950 to 1960. Here we examine the changes in these ratios.

Industries differ widely in proportions of total employment composed of engineers and chemists (Table II-16). In 1960, the three largest ratios were aircraft (12.8 percent), professional equipment (7.8 percent), and miscellaneous chemicals (7.6 percent). In 1950, aircraft (9.3 percent) and miscellaneous chemicals (7.1 percent) were in the top three, but the highest was radio and television communications (14.0 percent).

There does not appear to be a high degree of stability in the E. & C. ratios nor is there a uniform tendency toward increases in ratios. From 1940 to 1950, 8 of the 42 comparable industry ratios decreased and the rest increased. From 1950 to 1960, 20 of the 51 comparable industry group ratios decreased. Whether a ratio increases or decreases depends largely on industry characteristics and cannot be readily predicted statistically.

In their analysis of industrial patterns of use of scientists and engineers, Blank and Stigler /‾1957_7 derive a regression equation for 39 minor industry groups equivalent to /1

$$\frac{C^i_{50}}{E^i_{50}} = -0.0058 + 1.435 \; \frac{C^i_{40}}{E^i_{40}} \qquad (3)$$

/1 Note that the ratio equations are given in ratio, not percentage form, while the ratios are both tabled and discussed in percentage form.

Table II - 16

Chemists and Technical Engineers as Percent of Total Employment by Industry, 1940-60

Industry	1940	1950	1960
I. Mining, total	1.110	1.493	2.481
1. Coal mining	0.325	0.512	0.870
2. Petroleum and natural gas	2.013	3.127	3.781
3. Metal mining	2.991	2.936	3.298
4. Others, including quarries	1.448	1.338	1.694
II. Construction	1.960	2.270	2.487
III. Manufacturing	2.036	3.082	4.310
(Durable goods)[a]	2.029	3.101	5.102
1. Iron and steel industry	1.495	2.038	2.381
a. Blast furnaces, steel works	1.742	2.096	2.432
b. Other primary iron and steel	1.308	1.420	1.887
c. Miscellaneous iron and steel products		2.231	2.630[a]
2. Non-ferrous metal industries	1.617	2.475	4.668
a. Primary non-ferrous products	2.167	2.984	3.441
b. Miscellaneous non-ferrous products	1.182	1.415	5.129[a]
3. Not specified metal industries	1.307	2.237	2.933
4. Machinery	3.129	3.936	5.664
a. Electrical machinery and equipment	4.553	4.938	7.084

Chemists and Technical Engineers as Percent of Total Employment by Industry, 1940-60, Cont.

Industry	1940	1950	1960
b. Agricultural machinery	1.470	2.182	3.477
c. Office and store machinery	1.202	2.586	6.962
d. Miscellaneous machinery	2.652	3.620	4.046
5. Transportation equipment	1.593	3.161	6.111
a. Aircraft	4.551	9.261	12.795
b. Motor vehicles and equipment	1.168	1.588	2.552
c. Ships and boats	1.149	1.970	2.357
d. Railroads and miscellaneous transportation equipment	1.458	2.717	1.665
6. Professional equipment and instruments	1.976	4.010	7.109
a. Professional equip.	3.149	4.115	7.823
b. Photographic equip.		5.856	6.391
c. Watches, clocks, time pieces	0.633	1.203	1.837
(Nondurable goods)[a]	2.057	3.042	3.032
7. Food, drink, tobacco	0.530	0.884	0.775
8. Chemical and allied products	4.805	6.702	6.914
a. Synthetic fibers	2.210	4.160	4.412
b. Paints, varnishes, etc.	6.100	6.043	4.714
c. Drugs and medicines	5.037	6.260	5.376
d. Miscellaneous chemicals		7.109	7.639
9. Petroleum and coal products	5.223	6.575	5.307
a. Petroleum refining	5.487	6.917	5.568
b. Miscellaneous petroleum and coal products	3.190	3.322	3.006
10. Rubber products	1.909	2.097	2.492

Chemists and Technical Engineers as Percent of
Total Employment by Industry, 1940-60, Cont.

	Industry	1940	1950	1960
	Transportation, communication and other public utilities	1.283	1.407	1.525
IV.	Transportation	.385	.407	.392
	1. Air transportation	1.971	1.333	.745
	2. Railroad express service	.500	.447	.588
	3. Streetcars and buses	.445	.406	.309
	4. Trucking and taxicab	.020	.071	.070
	5. Warehouse and storage	.387	.863	.450
	6. Water transportation	.178	.236	.244
	7. Pipelines	2.526	4.896	4.913
	8. Incidental transportation services	.597	.723	.536
V.	Communications	1.729	2.150	2.414
	1. Postal services	.026	.033	.044
	2. Telephone	2.646	2.623	3.728
	3. Telegraph		1.102	1.310
	4. Radio and television	9.661	14.032	7.356
VI.	Utilities and sanitary services	4.352	4.058	3.624
	1. Electric light and power	5.541	5.093	4.813
	2. Gas supply	2.291	2.406	1.900
	3. Water supply		4.640	3.781
	4. Sanitary services	2.546	1.106	1.284
	5. Not specified utilities		3.902	3.514
VII.	Professional and related services			
	Excluding education	1.214	1.485	1.704
VIII.	Education	0.139	.373	0.297
	1. Government	NA	.322	0.244
	2. Private	NA	. 521	0.452

Chemists and Technical Engineers as Percent of
Total Employment by Industry, 1940-60, Cont.

Industry	1940	1950	1960
IX. Public administration			
Excluding armed forces	2.449	2.684	2.837
1. Federal government	3.802	3.643	4.337
2. State government	1.972	2.024	1.217
3. Local government		1.640	1.555
Subtotal above industries	1.581	2.130	2.684
All other industries[b]	.122	.249	0.327
Total all industries			
Excluding armed forces	.657	1.062	1.455

a. Not comparable to 1950. See appendix Table I Notes, Cont'd.

Source: Derived from Appendix Table I.

where C^i_{50} is employment of chemists and engineers in industry i in 1950, E^i_{50} is total employment in the same industry, and C^i_{40} and E^i_{40} are corresponding numbers. This equation they report to explain 90 percent of the variance in the 1950 ratios.

Repeating and updating these calculations, for 1950 the following equation is obtained (with the standard error of the regression coefficient written beneath the coefficient):

$$\frac{C^i_{50}}{E^i_{50}} = 0.0006 + \underset{(.074)}{1.288}\frac{C^i_{40}}{E^i_{40}} \qquad r^2 = 0.88 \tag{4}$$

No doubt the difference in equations result from our present practice of including major industry groups whenever they were not subdivided into minor industry groups.

The corresponding equation for 1960 is

$$\frac{C^i_{60}}{E^i_{60}} = 0.0069 + 0.828\ \frac{C^i_{50}}{E^i_{60}} \qquad r^2 = 0.70 \tag{5}$$

There are large differences between the 1950 and the 1960 equations. First, the intercept is quite small in 1950 equation (4) but it is fairly large in the 1960 equation. Second, the regression (or slope) coefficient is greater than unity in the 1950 equation, but smaller than unity in the 1960 equation. This suggests that the very large ratios in 1950 did not increase proportionately as much as the small ratios. The small intercept in the 1950 equation and the greater than unity regression coefficient suggest that all ratios increased by about 30 percent from 1940 to 1950. The 1950 to 1960 pattern is one of "topping out" or "catching up" in which most of the high ratio industries grew little, if at all. /1 The third important difference between the 1950 and 1960 equations is decline in the proportion of the total variance in the ratios explained by the regressions. This means that the relationship of the ratios became much less stable over the 1950 to 1960 decade, and can no longer be considered as impressive as the 1940 to 1950 relationship.

To determine the reasons for the change in the relationship, the residuals (actual ratio less ratio expected from the regression equation) are examined. The 1960 residuals were not at all normally distributed. /2 Manufacturing and nonmanufacturing industries were sharply differentiated: only 6 of the 23 manufacturing industries had negative residuals, and only 5 of the 28 manufacturing industries had positive residuals. Obviously combining manufacturing and non-manufacturing industries in a single equation results in a bad fit.

The industries with residuals larger in absolute value than one standard error are:

	1960 E & C Ratio		
	Actual	Expected	Residual
Electrical equipment	0.071	0.048	0.023
Office machinery	0.070	0.028	0.041
Aircraft	0.128	0.084	0.044
Professional equipment	0.078	0.041	0.037
Radio and television	0.074	0.123	-0.050

/1 The spreading of the ratios from 1940 to 1950 and the contraction of the spread of the ratios from 1950 to 1960 is seen in the coefficients of variation of the ratios which increased from 0.89 in 1940 to 0.93 in 1950 and then fell to 0.84 in 1960.

/2 29 of the 51 residuals are negative (25 or 26 are expected in a normal distribution). Only 5 residuals are larger in absolute value than one standard error of estimate (16 are expected in a normal distribution), and of these, 4 are larger than two standard errors (2 are expected in a normal distribution).

The four with positive residuals have large 1960 ratios, while the one with the negative residual experienced a large decrease from 1950 to 1960 in a E. & C. ratio that was very large in 1950. The sum of squared residuals of these five industries account for slightly more than four-fifths of the total sum of squared residuals not explained by the regression. In other words, if these residuals could be perfectly accounted for, the proportion of total variance explained would increase from 0.70 to 0.96.

The large negative residual of radio and television is explained by the maturation of the industry over the decade. From 1940 to 1950 the industry E. & C. ratio grew rapidly (the industry had a large positive residual from the 1950 regression). This growth was the result of the commercial exploitation of television during the late 1940's. The large proportion of engineers in the industry was accounted for by the newness and complexity of television equipment. With growing familiarity and technical stability in the industry, the need for technical engineers decreased.

The industries with large positive residuals all had large 1950 E. & C. ratios and these ratios grew markedly between 1950 and 1960. They are industries in which a very large fraction of the Nation's R. & D. performance is concentrated. They show positive residuals because these industries had growing E. & C. ratios that were already large in 1950, while the average ratio growth was quite small (from 0.29 in 1950 to 0.031 in 1960, or an average growth of 6.4 percent over the decade). Except for office machinery (digital computers), the R. & D. effort in these industries consists largely of military and space applications.

The importance of R. & D. performance in explaining the positive residuals of manufacturing industries in 1960 is obvious. Most industrial R. & D. is performed by manufacturing firms. The manufacturing industries with negative residuals in 1960 were railroad equipment; food, drink, and tobacco; paints and varnishes; drugs; petroleum refining; and miscellaneous petroleum and coal products. All of these had fairly large E. & C. ratios in 1950, but there was no large Federal R. & D. support in any of these industries during the 1950's, and neither R. & D. or E. & C. ratios grew exceptionally fast during the 1950's. The nonmanufacturing industries with positive residuals were petroleum extraction, metal mining, pipelines, telephone, and the Federal government. The Federal government is a large R. & D. performer, while the other industries are technologically progressive industries in which output has been growing while total employment has grown much less rapidly or even decreased over the period.

The residuals from the 1950 regression show a different pattern, although there are some similarities. First, the residuals are approximately normal. /1 Only 6 of the 20 manufacturing industries had negative residuals while 6 of 22 nonmanufacturing had positive residuals. The exceptionally large positive residual was aircraft, and the exceptionally large negative residual was electric light and power.

It was possible to match 39 industries for 1960 and 1950 residuals. Of these matched residuals, only 10 had different signs. If the signs were random, we would expect 19 or 20 matched signs. Of the four 1960 industries with

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/1 Of the 42 residuals, 22 were negative (21 negative residuals are expected); 11 residuals were larger than one standard error (13 are expected); and 2 residuals were larger than two standard errors (as expected).

exceptionally large positive residuals, three had positive residuals in 1950. Most industries had the same sign to residuals in 1950 and 1960. The persistence of positive residuals for manufacturing in 1950 and 1960 supports the association of positive residuals and the performance of R. & D. reported by Blank and Stigler for 1950.

The principle causes of departures from the average relationship for 1960 in E. & C. ratios appear to be R. & D. performance and technical maturity. The growth of R. & D. performance was traced in detail above, but technical maturity is discussed briefly here. An industry with complex technology may require a high proportion of technical manpower during a period of rapid growth, but with the leveling off of total employment that results from the slowing down of growth of output that comes with industrial maturity, the experienced but untrained labor force may be able to take on more and more of the functions once performed by trained engineers and technicians. This transition may occur with no reduction in the rate of productivity change and technological advance. I believe that electric light and power, gas supply, radio and television, and some of the chemical industries are examples of technically mature industries. I think a similar pattern would be observed in many manufacturing industires for non-R. & D. engineers. The reduction in E. & C. ratios that has occurred in many industries is not attributable exclusively to the opportunity provided by technical maturity. The opportunity has been taken up because the relative costs of engineers and scientists have been rising relative to most other industrial occupations, and because engineers are hard to hire, especially for jobs that do not require high level technical competence.

V. Research and Development Engineers and Scientists

In the three preceding sections it was shown that most of the increase in the ratio of engineers and chemists to total employment (E. & C. ratio) over the period 1940-1960 resulted from increases in employment and E. & C. ratios in manufacturing, especially durable goods manufacturing. These increases were traced to growth of R. & D. spending by the Federal government and by industry. In this section we examine the growth of R. & D. engineering and scientific employment directly; examining in turn: (1) changes in the distribution of primary functions of engineers and scientists; (2) industry employment by function; and (3) the growth of R. & D. employment by industry and its relation to the growth of R. & D. spending.

Functions of Engineers and Scientists

The number of engineers and scientists in R. & D. has grown steadily since 1941 (Table II-17). In 1950 only one-fifth of engineers and scientists were in R. & D., while in 1960 the proportion was one-third. Despite the rapid growth of R. & D. employment, the ratio of non-R. & D. engineers and scientists to total employment has increased considerably since 1950 (Table II-18). Available estimates of engineering and scientific functions show relatively large proportions of engineers engaged in administration, sales, and production. EPM's have large proportions in R. & D. functions and smaller proportions in production (Table II-19). The proportions of engineers and scientists in industry working in R. & D. varies considerably among scientific occupations. In the early 1960's about one-third of engineers were in R. & D., but more than half each of the mathematicians and of the physical scientists were in R. & D. These proportions represent considerable increases in proportions over earlier periods.

Table II-17

Employment of R. & D. Scientists and Engineers

Year	Total	Federal Government[e]	Industry	Other Nonprofit Institutions	Colleges and Universities
1941	87,000	17,000	62,000	8,000	
1942	90,000	18,000	64,000	8,000	
1943	97,000	21,000	67,000	9,000	
1944	111,000	27,000	72,000	12,000	
1945	119,000	29,000	76,000	14,000	
1946	122,000	28,000	80,000	14,000	
1947	125,000	25,000	84,000	16,000	
1948	133,000	25,000	90,000	18,000	
1949	144,000	26,000	94,000	24,000	
1950	151,000	25,000	100,000	26,000	
1951	158,000	28,000	104,000	26,000	
1952	180,000	33,000	118,000	29,000	
1954	223,200[a]	29,500[a]	164,100[a]	4,400[a]	25,200[a]
1957	NA	NA	229,400[c]	NA	NA
1958	327,100[a]	40,200[a]	243,800[a]	5,400[a]	42,000[a]
1959		40,865[b]	268,400[c]	NA	NA
1960	387,000[a]	41,800[a]	292,000[a]	7,000[a]	52,000[a]
1961	NA	45,903[b]	312,100[c]	NA	49,340[d]
1962	NA	50,843[b]	312,100[c]	NA	NA
1963	NA	NA	327,300[c]	NA	NA
1964	NA	NA	347,500[c]	NA	NA
1965	NA	NA	346,300[c]	NA	NA

Source for 1941-52: U.S. Department of Defense, The Growth of Scientific Research and Development, 1953, p. 12.

a. Fulltime equivalent. National Science Foundation, Reviews of Data on Research & Development, No. 33, April, 1962, Table 6, p. 6.

b. Estimated as of October in National Science Foundation, Scientific and Technical Personnel in the Federal Government, 1962. Relates to workers primarily engaged in R. & D. and is not fully comparable to estimates for other years.

c. Fulltime equivalent. National Science Foundation, Reviews of Data on Science Resources, no. 7, January, 1966.

d. Fulltime equivalent. National Science Foundation, Scientists and Engineers in Colleges and Universities, 1961.

e. Government for 1952 and before.

Table II-18

Scientists and Engineers in R. & D. and Other Functions, 1950 and 1960

	Engineers and Scientists				Engineers and Scientists as Percent of Total Employment[d]		
Year	Total[a]	R.& D.	NonR.&D.	R.&D. as % of Total	Total	NonR.&D.	R.&D.
1950	702,700	151,000[b]	551,700	22	1.3	1.0	0.3
1960	1,157,300	387,000[c]	770,300	33	1.8	1.2	0.6

a. Estimated by Bureau of Labor Statistics.

b. Estimated by Department of Defense (see Table II-17).

c. Estimated by National Science Foundation (see Table II-17).

d. For total employment see Appendix Table Ia.

Table II-19

Functions of Engineers and Scientists in Industry, 1962

Total	All Scientists Engineers	Engineers	Chemists	Physicists	Mathematicians
Total	100.0	100.0	100.0	100.0	100.0
R.&D.	30.1	27.2	47.4	72.1	48.4
Management and Administration					
R.&D.	5.5	5.1	8.3	12.6	4.6
Other	12.6	13.6	7.1	2.8	8.8
Technical Sales and Service	10.9	10.9	9.5	3.0	10.3
Production and Operations	34.3	36.9	24.6	7.0	19.0
All Other	6.5	6.3	3.0	2.4	9.0

Source: Bureau of Labor Statistics, Employment of Scientific and Technical Personnel in Industry, 1962, Bulletin 1418, 1964, Table A-10, pp. 34-35 and A-20, p. 51.

Industry Employment by Function

The proportion of engineers and scientists working in R. & D. varies considerably among industries (Table II-20). Research and development activities inherently demand engineering and scientific services. Indeed, one might define R. & D. as any activity that employs large proportions of engineers and scientists for purposes other than administration or teaching. Industries with large ratios of engineers and scientists to total employment (E. & S. ratios) also have large proportions of their engineers and scientists engaged in R. & D. (R. & D. proportions). In other words, R. & D. is a major reason for industries having large E. & S. ratios. When the E. & S. ratio is split between a R. & D. E. & S. ratio and a non-R. & D. ratio, there is a strong positive relationship between the two ratios. This is because manufacturing industries account for most industrial R. & D. performance and also have always had large E. & S. ratios. R. & D. is concentrated in aircraft, electrical equipment, chemicals, and professional equipment, industries with technologies that employed many engineers and scientists for production and test purposes even before formal R. & D. became important.

Growth of R. & D. Employment by Industry

The rate of growth of R. & D. employment over the period 1957 to 1964 is not highly correlated with the rate of growth of R. & D. spending (Table II-21). Departures from the expected relationship are best discussed in terms of R. & D. performance cost per R. & D. scientist and engineer (cost per researcher). A rise in cost per researcher occurs if spending increases faster than employment of R. & D. engineers and scientists. The most rapid increases during the period 1957-1964 were primary metal industries, drugs, "other" chemicals, and optical

Table II-20

Percent of Engineers and Scientists in R.&D. and
Ratios of R.&D. and Non-R.&D. Engineers and
Scientists to Total Employment, 1962

Industry	% of Engineers & Scientists in R.&D.[b]	Ratio of Engineers & Scientists to Total Employment		
		Total	R. & D.[b]	NonR. & D.
All nonagricultural industries[a]	35.7	3.0	1.1	1.9
Mining	9.6	1.9	0.2	1.7
Construction	1.5	2.5	0.0	2.5
Manufacturing[a]	43.3	3.8	1.7	2.1
Ordnance	50.3	18.3	9.2	9.1
Textiles	51.3	0.8	0.4	0.4
Lumber and wood	16.0	0.5	0.1	0.4
Paper	23.2	2.0	0.5	1.5
Chemical & Allied Products[a]	31.5	10.2	3.2	7.0
Industrial chemicals	37.7	11.3	4.3	7.0
Drugs	39.4	16.9	6.7	10.2
Petroleum	18.7	9.7	1.8	6.9
Rubber	36.9	2.0	0.7	1.3
Stone, Clay, & Glass	32.6	1.9	0.6	1.3
Primary Metals[a]	19.5	2.6	0.5	2.1
Blast furnace products	18.8	2.2	0.4	1.8
Fabricated Metals	24.8	2.2	0.5	1.7
Machinery[a]	38.3	4.6	1.8	2.8
Office machinery	63.8	9.5	6.1	3.4
Electrical Equipment	52.6	7.8	4.1	3.7
Communications equipment	59.7	12.3	7.3	5.0
Electronics equipment	41.7	7.0	2.9	4.1
Transportation Equipment	54.6	6.8	3.7	3.1
Aircraft	60.2	12.4	7.5	4.9
Professional and Scientific Instruments[a]	49.2	8.6	4.2	4.4
Eng'g & scientific instruments	45.2	17.7	8.0	9.7
Transportation, Communications, & Public Utilities	4.8	1.4	0.1	1.3
Engineering & Architectural Services	18.5	6.4	1.2	5.2
Commercial Laboratories & Business and Management Consulting	59.2	5.6	3.3	2.2

a. Includes industries not included in detail.
b. Includes research and development and management of research and development.

Source: Derived from Bureau of Labor Statistics, Employment of Scientific and Technical Personnel in Industry, 1962, Bulletin 1418, Washington, U.S. Government Printing Office, June, 1964.

Table II-21

Percentage Changes in R.& D. Spending, R.& D. Scientist and Engineer Employment, and Performance Cost Per R.& D. Scientist and Engineer, 1957-1964

Industry	1957-1964 % Change: R. & D. Spending	1957-1964 % Change: R. & D. Scientist & Engineer Employment	Performance Cost Per R.&D. Scientist and Engineer: 1957	Performance Cost Per R.&D. Scientist and Engineer: 1964	Performance Cost Per R.&D. Scientist and Engineer: % Change 1957-1964
Total	73	42	$32,675	$38,492	18
Food	82	17	17,209	25,000	45
Textiles	113	50	20,000	27,862	39
Lumber	-21	-38	17,500	22,000	26
Paper	62	53	21,875	28,077	28
Industrial	70	39	27,337	33,968	24
Drugs	126	49	21,224	31,757	50
Other Chemicals	97	1	14,203	25,229	78
Petroleum	48	20	29,510	38,295	30
Rubber	40	19	22,766	26,316	16
Primary Ferrous Metals	77	0	21,695	38,966	80
Primary Nonferrous Metals	77	45	20,000	34,666	73
Fabricated Metals	37	-18	16,168	22,857	41
Machinery	49	19	25,583	31,975	25
Communications & Electronics	97	91	36,048	34,988	-3
Other Electrical Equipment	9	26	42,840	35,183	-12
Motor Vehicles & Other Trans.	69	65	24,720	35,399	43
Aircraft and Missiles	96	73	43,887	49,853	14
Scientific Instruments	51	37	22,602	22,950	2
Optical and Surgical Instru.	148	69	24,719	37,397	51

instruments. R. & D. spending in each of these industries was largely private (see Table II-7 above). The smallest increases in cost per researcher were communications, "other" electrical equipment, scientific instruments, and aircraft, all of which were industries in which Federal R. & D. spending was a large proportion of R. & D. spending. One obvious explanation for this relationship is that firms spending their own money have substituted other factors for engineers and scientists as the prices of engineers and scientists have risen relative to other wages and prices, while firms spending the Federal government's money have been less ready to make this substitution. This explanation would be supported by relatively large ratios of R. & D. technicians to R. & D. engineers in "private R. & D." industries. There is no evidence of this, but of course technology varies between industries. [1] The lower rate of increase of cost per researcher in "Federal R. & D." industries might be merely nominal, but there is no evidence that these industries grant the title "engineer" to technicians more readily than "private R. & D." industries.[2]

This pattern of relationship supports the frequently heard criticisms of the Federal government and its contractors as wasteful in their utilization of engineers and scientists. Increased government spending in the major "Federal R. & D." industries has led to an even more rapid growth of employment of R. & D. engineers and scientists despite the rise of engineering and scientific salaries relative to most other wages and prices. It is possible that characteristics of Federal R. & D. activities may have changed enough to account for

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/1 This lack of relationship is seen in the R. & D. technician/R. & D. engineer and scientist ratios in Bureau of Labor Statistics [1963] Table 9, p. 24.

/2 The industry proportions of graduate engineers to all engineers as of December 31, 1962 are not related to industries with large cost per researcher increases. Graduate proportions can be derived from Engineering Manpower Commission of Engineers Joint Council [1959], Appendix Tables I-IV.

an increase in the proportion of the R. & D. dollar spent on engineers and scientists. The shift to manned spaceflight and efforts to obtain increased reliability and modifications in existing weapon systems may account for the change in requirements, but this does not seem likely. Space research has a high performance cost per R. & D. scientist and engineer. In 1963, NASA accounted for about one-sixth of R. & D. spending but only one-fifteenth of all R. & D. scientists and engineers (Table II-22).

One of the major factors in changing industry composition of R. & D. employment is the Nation's space program. NASA accounts for about three-fourths of the Nation's space spending, and the Department of Defense and the Atomic Energy Commission for most of the rest. NASA's proportion of total R. & D. spending has increased from 3 percent in 1960 to more than 15 percent in 1963. This proportion also rose in 1964, but it has probably peaked and will decline after fiscal year 1965 as a proportion of total R. & D. spending. The growth of employment of engineers and scientists in NASA programs from 1 percent of all engineers and scientists in 1960 to 5 percent of the total in 1964 led to major differences in industry R. & D. employment. Fulltime equivalent R. & D. scientists and engineers increased by one-half in aircraft from January 1, 1960 to January 1, 1964 (from 74.2 thousand to 108.9 thousand) while total R. & D. fulltime equivalent employment increased only 11 percent. /1

/1 National Science Foundation [1966], Table 5.

Table II-22

Employment of Engineers and Scientists and
NASA Engineers and Scientists, 1960-64
(number in thousands)

	Engineers and Scientists in NASA Programs				Engineers and Scientists in United States		NASA Program Engineers and Scientists as % of Total		NASA R.&D. Spending as % of Total R.&D. Spending[e]
Jan. 1	Total	NASA	Contractor[a]	Total R.&D.[b]	Total	R.&D[d]	Total	R. & D.	
1960	8.4	3.4	5.0	7.5	1,185	420	0.7	1.8	3.2
1961	14.7	5.2	9.5	13.0	1,260	460	1.2	2.8	5.4
1962	22.0	6.3	15.7	18.8	1,340	495	1.6	3.8	8.5
1963	43.5	9.2	34.3	35.7	1,415	530	3.1	6.7	15.6
1964	73.7	11.5	62.2	60.0	1,497	570	4.9	10.5	NA

a. Estimated by NASA from a sample of contractors.

b. Estimated by NASA by applying percentages of R. & D. scientists and engineers to estimates of all engineers and scientists in six end use categories.

c. For 1960-63 estimates for employment in U.S. Department of Labor, The Manpower Report of the President, 1963, pp. 100 and 125. 1964 derived by interpolation between 1960 and 1970 estimated requirements of 1,955,000.

d. Derived by NASA by interpolating linearly between 36.6 percent in 1960 and 42.0 percent in 1970 and applying resulting percentages to estimated total employment of engineers and scientists. The 1960 and 1970 percentages are derived from Bureau of Labor Statistics, Scientists, Engineers, and Technicians in the 1960's--Requirements and Supply, National Science Foundation, 1964.

e. NASA expenditures from Table II-8. Total R. & D. estimates based on the "hyphenated year" concept in National Science Foundation, Reviews of Data on Research & Development, No. 41, September, 1963.

Source: Allen O. Gamble and C. Guy Ferguson, An Analysis of the Requirements for, and Recruitment of, Scientists and Engineers, National Aeronautics and Space Administration, (Draft), January 31, 1964.

VI. Demand for Occupational Specialties

Up to this point I have treated the demand for engineers, physical scientists, and mathematicians (EPM's) as if it were homogeneous. This assumption will be relaxed for the rest of the analysis. Indeed, one of our principal concerns is the process by which the demands for and supplies of EPM specialties are meshed. The purpose of this section is to describe the pattern of industry specialization in EPM specialties and to lay the ground work for a more detailed analysis of labor market adjustment (preliminary treatment of which is given in Folk [1956[b]]). The rapid growth of employment of mathematicians and physicists has been a result of the growth of R. & D. In 1950 Blank and Stigler [1957] report that only 1,510 mathematicians of 7,359 total and only 6,930 physicists out of 11,520 total were employed in jobs other than college and university instructor. By 1962, a survey of private industry employment showed that 14 thousand physicists and 15 thousand mathematicians were employed (Table II-23), a majority of whom were in R. & D. Industry specialization in the employment of EPM's depends naturally on the importance of R. & D. in the various industries. The pattern of growth in R. & D. will effect the industry proportions of the EPM specialties.

Currently scientists are industrially specialized. About one-third of all scientists and almost one-half of chemists in private industry are employed in chemicals and allied products. About one-fourth of all physicists are employed in electrical equipment. Metallurgists and geologists are concentrated respectively in the metal industries and in petroleum refining and extraction. About three-tenths of all scientists and engineers are employed in ordnance, electrical equipment, and aircraft and parts combined, which are the industries primarily concerned with military and space R. & D.

Table II-23

Scientists and Engineers in Private Industry, Percentage Distributions of Scientific Specialties in Selected Industries, 1962

Industry	Engineers and Scientists	Engineers	Total Scientists	Chemists	Physicists	Metallurgists	Earth Scientists	Mathematicians	Life Scientists	Other Scientists
Total	100	100	100	100	100	100	100	100	100	100
Ordnance	5	5	2	1	7	2	(a)	4	(a)	(a)
Chemicals	11	6	34	45	13	4	(a)	5	61	22
Petroleum	4	3	7	4	1	(a)	72	2	1	(a)
Primary & Fabricated Metals	7	7	7	5	1	52	1	3	(a)	(a)
Machinery	8	9	3	2	6	8	1	12	(a)	4
Electrical	14	16	7	4	28	6	(a)	18	(a)	14
Aircraft & Parts	10	11	5	2	12	10	2	16	1	18
Instruments	4	4	3	2	10	1	3	3	1	4
Other Mfg.	11	10	16	20	4	6	2	4	24	32
Services	10	11	7	5	15	5	5	13	7	2
Other Nonmfg.	16	18	9	10	2	6	9	20	5	4
No. (thousands)	1,018.6	851.6	167.0	81.6	13.9	12.4	12.9	14.7	26.5	5.0

a. less than 0.5 percent.

Source: Derived from Bureau of Labor Statistics, Employment of Scientific and Technical Personnel in Industry, 1962, Bulletin 1418, Washington, U.S. Government Printing Office, June 1964.

The academic engineering specialties correspond to industrial specialties. For instance, the student chemical engineer studies the technology of the chemical and oil refining industries, while the electrical engineering student learns the technology of electronics, communications, or power, depending on his option. Not all engineers in a particular academic specialty enter the corresponding industrial specialty. For instance, not all graduates in electrical engineering become electrical engineers. Moreover, not all engineers in an industrial specialty work in the corresponding industry. That is to say not all electrical engineers work in the electronics, communications, or power industries.

The flow from academic to industrial specialty examined elsewhere (see Folk [1965[d]]). Here the relationship between industrial specialty and industry and the change in this relationship is examined. An industry will be said to be highly <u>specialized in its demand for engineers</u> if a large proportion of its engineers are in one specialty. In this sense the construction and communications industries are highly specialized in their demand. In 1960, 84 percent of the engineers in construction were civil engineers and 88 percent of the engineers in communications were electrical engineers (Table II-24). An industrial specialty will be said to be highly <u>specific to an industry</u> if a large proportion of the engineers in the specialty are employed in the industry. Thus in 1960, aeronautical and mining engineering were highly specific: 83 percent of aeronautical engineers were employed in aircraft and parts and 66 percent of mining engineers were employed in mining.

There is no strong relationship between changes in industry specialization and changes in industrial specificity in the period 1950 to 1960. Some

Table II-24

Industry and Industrial Specialty of Engineers 1950 and 1960

Industry	Industrial Specialty	% of Engineers in Industry with Industry Specialty		% of Engineers in Industrial Specialty in Industry	
		1950	1960	1950	1960
Aircraft and Parts	aeronautical	57.1	51.5	75.9	83.0
Chemical and Allied	chemical	52.2	53.0	34.9	42.5
Machinery (exc. electrical)	mechanical	50.0	46.0	19.6	19.3
Electrical Machinery	electrical	59.9	57.9	21.1	32.7
Primary Metals	metallurgical	29.7	32.6	48.9	46.3
Fabricated Metals	mechanical	34.9	34.5	5.4	11.2
Petroleum and Coal Products	chemical	30.9	40.5	14.0	11.7
Transportation Equipment (except aircraft)	Mechanical	45.2	52.3	7.5	9.2
Construction	civil	76.5	83.9	48.4	49.1
Mining	mining	49.6	55.1	54.1	66.1
Communications	electrical	80.4	87.8	12.3	15.8
Transportation	civil	39.0	37.0	3.7	2.5
Utilities	electrical	53.7	49.2	15.5	8.4
Government	civil	43.9	33.2	17.9	14.9

Source: Appendix Tables II-2 and II-3.

industries became less specialized while the corresponding specialties became more specific. This was the case with aircraft and parts and electrical machinery. Both of these industries had large increases in engineering employment, and both of the corresponding specialties were in very short supply during the period 1950 to 1960. Other industries became more specialized while the corresponding industrial specialties and became less specific. This was true of petroleum and coal products and primary metals, industries in which engineering employment grew slowly or decreased. Industries that grew more specialized while the corresponding industrial specialties grew more specific were chemical and allied products, construction, mining, communications, and transportation equipment. Of these, only communications had a higher than average increase in engineering employment. The first three industries were specialized in specialties that had relatively plentiful supplies during the decade. The other industries showed both decreases in specialization and decreased specificity in the corresponding engineering specialties.

While the relationship between industry and industrial specialty is not strong, it does not contradict the pattern of relatively extreme shortages of electrical and aeronautical engineers deduceable from job vacancy and starting salary data (see Folk [1965[b]]).

APPENDIX TABLE I a

Total Employment, by Industry, 1940-60

Industry	Total Employment 1940	Total Employment 1950	Total Employment 1960
I. Mining, Total	907,520	928,260	653,979
1. Coal mining	523,680	510,180	201,285
2. Petroleum and natural gas	181,860	233,160	252,984
3. Metal mining	116,340	92,970	94,908
4. Others, including quarries	85,640	91,950	104,802
II. Construction	2,094,220	3,398,040	3,717,678
III. Manufacturing*[a]	5,626,440	8,228,910	11,346,517
(Durable goods)	3,617,300	5,581,590	7,736,946
1. Iron and steel industry	1,267,280	1,660,560	1,381,578
a. Blast furnaces, steel works	545,300	661,380	620,394
b. Other primary iron and steel	721,980	285,180	298,141
c. Miscellaneous iron and steel products	721,980	714,000	463,043[c]
2. Non-ferrous metal industries	202,880	320,040	1,131,267
a. Primary non-ferrous products	89,520	216,120	308,847
b. Miscellaneous non-ferrous products	113,360	103,920	822,420[d]
3. Not specified metal industries	38,260	13,410	6,785
4. Machinery	1,073,180	2,054,610	3,040,034
a. Electrical machinery and equipment	372,940	770,970	1,480,209
b. Agricultural machinery	91,140	178,770	120,696
c. Office and store machinery	61,560	105,570	168,766
d. Miscellaneous machinery	547,540	999,300	1,270,363
5. Transportation equipment	879,840	1,336,230	1,819,604
a. Aircraft	107,680	257,220	644,390
b. Motor vehicles and equipment	575,480	863,400	838,935
c. Ships and boats	151,420	153,780	250,576
d. Railroads and miscellaneous transportation equipment	45,260	61,830	85,703
6. Professional equipment and instruments	155,860	196,740	357,678
a. Professional equipment	83,200	115,200	266,214
b. Photographic equipment	83,200	46,620	64,135
c. Qatches, clocks, time pieces	72,660	34,920	27,329
(Nondurable goods)[a]	2,009,140	2,647,320	3,109,571
7. Food, drink, tobacco	1,207,940	1,472,550	1,692,582
8. Chemical and allied products	440,820	654,480	857,786
a. Synthetic fibers	52,480	53,370	56,068
b. Paints, varnishes, etc.	43,280	57,090	67,135
c. Drugs and medicines	345,060	57,030	108,171
d. Miscellaneous chemicals	345,060	486,990	626,412

Total Employment, by Industry, 1940-60, Cont.

Industry	Total Employment 1940	Total Employment 1950	Total Employment 1960
9. Petroleum and coal products	202,180	284,280	281,353
a. Petroleum refining	178,980	257,190	252,714
b. Miscellaneous petroleum and coal products	23,200	27,090	28,639
10. Rubber products	158,200	236,010	277,830
Transportation communication and other public utilities	3,414,540	4,869,460	5,009,412
IV. Transportation	2,176,460	2,927,010	2,739,399
1. Air transportation	22,320	94,500	177,410
2. Railroad express service	1,137,000	1,381,740	944,428
3. Streetcars and buses	202,320	325,200	292,843
4. Trucking and taxicab	511,520	765,260	922,091
5. Warehouse and storage	62,060	97,350	112,248
6. Water transportation	180,240	203,250	189,244
7. Pipelines	17,420	20,220	20,821
8. Incidental transportation services	43,580	41,490	60,314
V. Communications	703,140	1,163,950	1,372,509
1. Postal services	309,240	460,510	550,863
2. Telephone	370,300	594,750	692,480
3. Telegraph	370,300	46,260	40,077
4. Radio and television	23,600	62,430	89,089
VI. Utilities and Sanitary Services	534,940	778,500	897,504
1. Electric light and power	329,880	448,890	488,844
2. Gas supply	86,440	114,720	145,570
3. Water supply	118,620	73,700	97,641
4. Sanitary services	118,620	105,820	146,981
5. Not specified utilities	118,620	35,370	18,468
VII. Professional and Related Services			
Excluding Education	1,749,880	2,572,020	4,189,265
VIII. Education	1,570,120	2,076,630	3,385,207
1. Government	N.A.	1,547,010	2,529,947
2. Private	N.A.	529,620	855,260
IX. Public Administration			
Excluding Armed Forces	1,147,180	2,030,160	2,643,387
1. Federal government	299,280	1,006,260	1,266,101
2. State government	847,900	266,760	396,491
3. Local government	847,900	757,140	980,795
Subtotal Above Industries	16,509,900	24,103,480	30,945,445
All Other Industries [b]	28,569,960	31,700,040	33,701,118
Total all Industries (Excluding armed forces)	45,079,860	55,803,520	64,646,563

APPENDIX TABLE I b

Employment of Chemists and Technical Engineers
By Industry, 1940-60

Industry	Total Employment 1940	Total Employment 1950	Total Employment 1960
I. Mining, Total	10,080	13,860	16,222
1. Coal mining	1,700	2,610	1,752
2. Petroleum and natural gas	3,660	7,290	9,565
3. Metal mining	3,480	2,730	3,130
4. Other, including quarries	1,240	1,230	1,775
II. Construction	41,040	77,130	92,473
III. Manufacturing[a]	114,560	235,580	488,979
(Durable goods)	73,400	173,060	394,702
1. Iron and steel industries	18,940	33,840	32,893
a. Blast furnaces, steel works	9,500	13,860	15,090
b. Other primary iron and steel	9,440	4,050	5,627
c. Miscellaneous iron and steel products	9,440	15,930	12,176 c
2. Non-Ferrous Metal Industries	3,280	7,920	52,806
a. Primary non-ferrous products	1,940	6,450	10,626
b. Miscellaneous non-ferrous products	1,340	1,470	42,180 d
3. Not specified metal industries	500	300	199
4. Machinery	33,580	80,870	172,189
a. Electrical machinery and equipment	16,980	38,070	104,844
b. Agricultural machinery	1,340	3,900	4,197
c. Office & store machinery	740	2,730	11,749
d. Miscellaneous machinery	14,520	36,170	51,399
5. Transportation equipment	14,020	42,240	111,187
a. Aircraft	4,900	23,820	82,447
b. Motor vehicles & equipment	6,720	13,710	21,406
c. Ships and boats	1,740	3,030	5,907
d. Railroads & miscellaneous transportation equipment	660	1,680	1,427
6. Professional equipment and instruments	3,080	7,890	25,428
a. Professional equipment	2,620	4,740	20,827
b. Photographic equipment	2,620	2,730	4,099
c. Watches, clocks, timepieces	460	420	502
(Nondurable goods) a	41,320	80,520	94,277
7. Food, drink, tobacco	6,400	13,020	13,116

Employment of Chemists and Technical Engineers
By Industry, 1940-60, Cont.

Industry	Total Employment 1940	Total Employment 1950	Total Employment 1960
8. Chemical & allied products	21,180	43,860	59,306
a. Synthetic fibers	1,160	2,220	2,474
b. Paints, varnishes, etc.	2,640	3,450	3,165
c. Drugs and medicines	17,380	3,570	5,815
d. Miscellaneous chemicals	17,380	34,620	47,852
9. Petroleum & coal products	10,560	18,690	14,932
a. Petroleum refining	9,820	17,790	14,071
b. Miscellaneous petroleum & coal products	740	900	861
10. Rubber products	3,020	4,950	6,923
Transportation, Communication & Other Public Utilities	43,820	68,520	76,398
IV. Transportation	8,380	11,910	10,742
1. Air transportation	440	1,260	1,322
2. Railway express service	5,680	6,180	5,557
3. Streetcars and buses	900	1,320	906
4. Trucking and taxicab	100	540	644
5. Warehouse and storage	240	840	505
6. Water transportation	320	480	462
7. Pipelines	440	990	1,023
8. Incidental transportation	260	300	323
V. Communications	12,160	25,020	33,132
1. Postal services	80	150	240
2. Telephone	9,800	15,600	25,814
3. Telephone	9,800	510	525
4. Radio and television	2,280	8,760	6,553
VI. Utilities & Sanitary Service	23,280	31,590	32,524
1. Electric light and power	18,280	22,860	23,530
2. Gass supply	1,980	2,760	2,766
3. Water supply	3,020	3,420	3,692
4. Sanitary services	3,020	1,170	1,887
5. Not specified utilities	3,020	1,380	649
VII. Professional & Related Services			
Excluding Education	21,240	38,190	71,367
VIII. Education	2,180	7,740	10,038
1. Government	N.A.	4,980	6,172
2. Private	N.A.	2,760	3,866

Employment of Chemists and Technical Engineers
By Industry, 1940-60, Cont.

	Industry	Total Employment 1940	Total Employment 1950	Total Employment 1960
IX.	Public Administration			
	Excluding Armed Forces	28,100	54,480	74,994
	1. Federal government	11,380	36,660	54,917
	2. State government	16,720	5,400	4,825
	3. Local government	16,720	12,420	15,252
	Subtotal Above Industries	261,020	513,500	830,471
	All Other Industries	34,980	79,000	110,196
	Excluding Armed Forces	296,000	592,500	940,667

FOOTNOTES

NA = not available

a. Includes industries listed under the heading; excludes manufacturing industries included in "All other industries," enumerated in footnote b.

b. Includes agriculture, forestry, fisheries; the following manufacturing industries: lumber and wood products glass products, stone and clay products, textiles and clothing, paper and printing, leather and leather products; and nonmanufacturing industries wholesale and retail trade, finance, insurance, and real estate, business and repair service, entertainment and recreation, and personal services.

c. Includes cutlery and hand tools, and fabricated structural metal products (not all of which may be iron and steel). Not fully comparable to 1950.

d. Miscellaneous fabricated metal products (not all of which are nonferrous). Not fully comparable to 1950.

Census of Population, 1940, The Labor Force, Occupational Characteristics, Table 19 (based on a 5% sample).

Census of Population, 1950, Special Report P.E. 1C, Occupation by Industry (based on a 3-½% sample).

Census of Population, 1960, Special Report PC (2)-7C, Occupation by Industry (based on a 5% sample).

APPENDIX TABLE II-2

Distribution of Engineers in Industry By Engineering Specialty, 1950 and 1960

		All Engineers		Engineering Specialty		
		Number	Total	Aero-nautical	Chem-ical	Civil
Total	1950	517,650	100.0	3.4	6.0	23.4
	1960	859,547	100.0	5.9	4.8	18.2
Aircraft	1950	23,430	100.0	57.1	0.6	2.0
	1960	81,424	100.0	51.5	1.3	2.8
Chemical	1950	20,640	100.0	0.4	52.2	4.8
	1960	32,520	100.0	0.1	53.0	4.8
Machinery	1950	41,940	100.0	0.1	1.3	2.4
	1960	66,325	100.0	0.2	1.2	1.4
Electrical Machinery	1950	37,140	100.0	0.2	1.8	1.5
	1960	103,222	100.0	0.3	1.7	0.7
Primary Metals	1950	20,730	100.0	0.7	4.1	9.3
	1960	26,826	100.0	0.1	2.6	5.3
Fabricated Metals	1950	16,680	100.0	0.7	3.2	9.2
	1960	52,648	100.0	6.2	2.3	5.2
Petroleum	1950	13,980	100.0	0.2	30.9	11.4
	1960	11,680	100.0	0.0	40.5	11.6
Transportation (excluding aircraft)	1950	17,790	100.0	0.5	2.7	4.4
	1960	27,953	100.0	0.8	1.1	2.7
Other Manufacturing Industries	1950	42,000	100.0	0.4	13.3	5.5
	1960	69,752	100.0	0.4	8.1	3.4
Total Manufacturing	1950	234,330	100.0	6.1	10.2	4.7
	1960	427,350	100.0	9.8	7.1	3.0
Construction	1950	76,680	100.0	0.2	1.0	76.5
	1960	91,952	100.0	0.0	0.6	83.9
Mining	1950	12,090	100.0	0.0	6.2	11.7
	1960	14,482	100.0	0.3	9.1	7.0
Communications	1950	16,080	100.0	0.2	0.6	3.7
	1960	32,851	100.0	---	0.1	3.0
Transportation	1950	11,460	100.0	4.5	0.5	39.0
	1960	10,483	100.0	4.4	1.7	37.0
Utilities	1950	30,270	100.0	0.1	2.2	18.1
	1960	31,018	100.0	0.1	1.4	22.1
Professional & Related Services	1950	32,580	100.0	0.6	4.9	32.5
	1960	64,204	100.0	0.5	2.3	35.3
Other Nonmanufacturing	1950	49,530	100.0	0.0	3.6	11.1
	1960	64,635	100.0	1.2	3.2	8.9
Education	1950	5,250	100.0	2.9	4.6	30.9
	1960	7,127	100.0	3.7	2.6	19.5
Government	1950	49,380	100.0	4.6	2.0	43.9
	1960	70,445	100.0	3.3	1.2	33.2

Distribution of Engineers in Industry Be Engineering Specialty, 1950 and 1960 (continued)

		Engineering Specialty					
		Electrical	Industrical	Mechanical	Metallurgical	Mining	Other (nec)
Total	1950	20.3	7.7	20.7	2.4	2.1	13.9
	1960	21.2	11.2	18.4	2.2	1.4	16.8
Aircraft	1950	9.5	5.1	18.7	2.2	0.0	4.7
	1960	14.1	9.0	16.7	1.4	0.0	3.1
Chemical	1950	7.1	9.0	17.3	0.6	0.4	8.1
	1960	4.7	9.2	17.2	2.0	0.2	8.9
Machinery	1950	8.0	11.4	50.0	2.8	0.5	23.5
	1960	9.5	13.9	46.0	2.2	0.2	25.5
Electrical Machinery	1950	59.9	8.0	13.6	1.6	0.0	13.5
	1960	57.9	12.0	13.3	1.2	0.1	13.1
Primary Metals	1950	4.3	17.8	19.7	29.7	0.9	13.6
	1960	5.5	24.0	17.5	32.6	0.4	12.1
Fabricated Metals	1950	5.6	12.1	34.9	5.6	0.2	28.6
	1960	15.2	14.4	34.5	4.6	---	18.4
Petroleum	1950	4.7	4.5	24.0	0.4	15.5	8.4
	1960	2.9	5.8	17.4	0.3	10.4	11.0
Transportation (excluding aircraft)	1950	11.3	14.5	45.2	5.2	0.2	16.0
	1960	8.0	19.8	52.3	2.4	---	12.8
Other Manufacturing Industries	1950	8.6	19.1	29.0	0.8	0.2	23.1
	1960	13.0	21.4	19.8	0.5	0.2	31.8
Total Manufacturing	1950	16.0	11.8	28.8	4.6	1.2	11.6
	1960	21.0	14.2	24.6	3.5	0.1	16.0
Construction	1950	7.0	1.1	10.3	0.1	0.4	3.4
	1960	4.0	1.5	6.0	0.1	0.1	3.8
Mining	1950	7.7	4.0	11.2	2.7	49.6	6.9
	1960	5.8	6.3	7.5	2.4	55.1	7.0
Communications	1950	80.4	2.4	5.2	0.0	0.2	7.3
	1960	87.8	2.0	1.7	0.0	0.0	5.4
Transportation	1950	18.1	4.5	23.8	2.6	2.4	7.1
	1960	13.8	10.1	23.2	0.2	1.7	7.9
Utilities	1950	53.7	4.3	13.8	0.1	0.1	7.6
	1960	49.2	3.7	13.0	0.3	0.3	9.9
Professional & Related Services	1950	14.9	4.9	17.3	1.0	1.6	22.3
	1960	12.6	3.8	16.4	0.8	1.0	27.2
Other Manufacturing	1950	30.8	10.7	20.6	1.0	1.2	21.2
	1960	17.1	1.5	11.7	1.1	1.1	39.5
Education	1950	23.4	2.2	18.2	1.7	2.2	13.7
	1960	27.1	4.0	18.7	2.3	0.3	22.0
Government	1950	18.0	3.8	12.1	0.9	1.0	13.8
	1960	15.2	16.2	11.2	0.5	0.9	17.6

Source: U.S. Department of Commerce, Bureau of the Census, Census of Population, 1950, Special Report P.E. 1C; Census of Population, 1960, Special Report PC (2)-7C, Occupation By Industry (based on a 5 percent sample).

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APPENDIX TABLE II-3

Percentage Distribution of Engineering Specialties by Industry, 1950 and 1960

	All Engineers		Aeronautical		Chemical		Civil		Electrical	
	1950	1960	1950	1960	1950	1960	1950	1960	1950	1960
Aircraft	4.5	9.5	75.9	83.0	0.5	2.7	0.4	1.5	2.1	6.3
Chemical	4.0	3.8	0.5	0.1	34.9	42.5	0.8	1.0	1.4	0.8
Machinery	8.1	7.7	0.3	0.2	1.8	1.9	0.8	0.6	3.2	3.5
Electrical Machinery	7.2	12.0	0.5	0.7	2.1	4.2	0.4	0.4	21.1	32.7
Primary Metals	4.0	3.1	0.9	0.0	2.7	1.7	1.6	0.9	0.9	0.8
Fabricated Metals	3.2	6.1	0.6	6.5	1.8	3.1	1.3	1.8	0.9	4.4
Petroleum	2.7	1.4	0.2	0.0	14.0	11.7	1.3	0.8	0.6	0.2
Transportation (excluding aircraft)	3.4	3.2	0.5	0.4	1.6	0.8	0.6	0.5	1.9	1.2
Other Manufacturing Industries	8.2	8.1	1.0	0.6	18.0	13.9	2.0	1.5	3.4	5.0
(Total manufacturing	(45.3)	(54.9)	(80.4)	(91.5)	(77.4)	(82.5)	(9.2)	(8.9)	(35.5)	(54.9)
Construction	14.8	10.7	0.6	0.0	2.5	1.3	48.4	49.1	5.1	2.0
Mining	2.3	1.7	0.0	0.1	2.4	3.2	1.2	0.6	0.9	0.5
Communications	3.1	3.8	0.2	0.0	0.3	0.1	0.5	0.6	2.3	15.8
Transportation	2.2	1.2	2.9	0.9	0.2	0.4	3.7	2.5	2.0	0.8
Utilities	5.8	3.6	0.2	0.0	2.1	1.1	4.5	4.4	15.5	8.4
Professional & Related Services (excluding education)	6.3	7.5	1.2	0.7	5.2	3.7	8.7	14.4	4.6	4.4
Other Nonmanufacturing	9.7	7.5	0.9	1.6	5.9	5.1	4.6	3.6	4.4	6.1
Education	1.0	0.8	0.9	0.5	0.8	0.4	1.3	0.9	1.2	1.1
Government	9.5	8.2	12.7	4.6	3.2	2.1	17.9	14.9	8.5	5.9
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
(Number)	517,650	859,547	17,640	50,554	30,840	40,501	121,170	157,134	105,240	181,875
Percent Increase $\frac{1960}{1950}$		66.0		186.6		31.3		29.7		72.8

APPENDIX TABLE II-3 (continued)

Percentage Distribution of Engineering Specialties by Industry, 1950 and 1960

	Industrial		Mechanical		Metallurgical		Mining		Other (nec)	
	1950	1960	1950	1960	1950	1960	1950	1960	1950	1960
Aircraft	4.1	7.7	4.1	8.6	4.0	6.8	0.0	0.2	1.5	1.7
Chemical	3.3	3.1	3.3	3.5	1.0	3.4	0.8	0.7	2.3	2.0
Machinery	19.6	19.6	19.6	19.3	9.3	7.6	1.9	0.8	13.8	11.7
Electrical Machinery	4.7	12.9	4.7	8.7	4.8	6.4	0.0	0.5	7.0	9.4
Primary Metals	3.8	6.7	3.8	3.0	48.9	46.3	1.6	0.8	3.9	2.2
Fabricated Metals	5.4	7.9	5.4	11.2	7.3	12.8	0.3	0.0	6.7	6.7
Petroleum	3.1	0.7	3.1	1.3	0.5	0.2	19.5	10.1	1.6	0.9
Transportation (excluding aircraft)	7.5	5.8	7.5	9.2	7.3	3.6	0.3	0.0	4.0	2.5
Other Manufacturing Industries	11.4	15.5	11.4	8.7	2.7	1.8	0.7	1.2	13.6	15.4
(Total manufacturing)	(62.9)	(69.9)	(62.9)	(73.5)	(85.8)	(88.9)	(25.1)	(14.3)	(54.4)	(52.5)
Construction	7.4	1.4	7.4	3.5	0.5	0.4	2.7	1.0	3.6	2.4
Mining	1.3	1.0	1.3	0.7	2.6	1.8	54.1	66.1	1.2	0.7
Communications	0.8	0.7	0.8	0.4	0.0	0.0	0.3	0.0	1.6	1.2
Transportation	2.5	1.1	2.5	1.5	0.2	0.1	2.4	1.5	1.1	0.6
Utilities	3.9	1.2	3.9	2.6	0.2	0.5	0.3	0.7	3.2	2.1
Professional & Related Services (excluding education)	5.3	2.6	5.3	6.7	2.6	2.8	4.6	5.2	10.1	12.1
Other Nonmanufacturing	9.4	9.9	9.4	4.8	4.1	3.7	5.0	5.9	15.0	17.7
Education	0.9	0.3	0.9	0.8	0.7	0.8	1.1	0.2	1.0	1.1
Government	5.6	11.9	5.6	5.0	3.3	1.9	4.4	5.2	8.8	9.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
(Number)	40,040	96,063	107,220	158,071	12,600	18,922	11,100	12,002	71,700	144,425
Percent Increase $\frac{1960}{1950}$		139.9		47.4		50.2		8.1		101.4

Source: U.S. Department of Commerce, Bureau of the Census, Census of Population, 1950, Special Report P.E. 1C; Census of Population, 1960, Special Report PC (2) - 7C, Occupation by Industry (based on a 5 percent sample).

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