Special Study No 6

Background Studies in Science Policy:

Projections of R&D Manpower and Expenditure

by

R. W. Jackson, D. W. Henderson and B. Leung

Prepared for

The Science Council of Canada

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FOREWORD

The three studies comprising this report were undertaken by staff members of the Science Secretariat in direct support of Science Council Report No. 4, *Towards a National Science Policy for Canada*, and are presented as helpful background material to that report.

The projections contained in these reports are, as the authors point out, based on assumptions that may or may not be borne out in fact. However the assumptions are reasonable in the light of all evidence available now and projections had to be made if progress was to be made in developing a national science policy.

The staff of the Science Council will be grateful for any comments or criticism which will lead to an improvement of these projections.

As in the reports already published in this series, opinions expressed in this report are those of the authors and should not be attributed to the Science Secretariat, the Science Council, or to the Government of Canada.

P. D. McTaggart-Cowan,
Executive Director,
Science Council of Canada.

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Section 1

THE PROJECTED SUPPLY OF SCIENTISTS AND ENGINEERS IN CANADA*

This Section attempts to project the most likely size of the engineering and scientific work force in Canada to the year 1978. To do this we begin with published data up to 1966–67, then estimate the net input year by year from university graduations and immigration, less an attrition rate due to deaths, retirements, and job changes. The possible effects of shifts in demand, in student motivations, in statistical definitions, and in external factors such as immigration are taken into account as far as feasible.

International comparisons are attempted only with the United States, as the only country with social structure and economy similar enough to the Canadian that the statistical categories have reasonably similar meanings.

Present Status of the Professional Work Force

The total Canadian labour force numbered 7.4 million in 1966, compared to 79 million in the United States.[1] The growth rate of the Canadian labour force over the postwar period has been faster, at 2.4 percent per annum, compared to 1.4 per cent for the United States. The current growth rates are particularly high (3.2 per cent in Canada, 1.8 per cent in the United States).[9,10] The general trends are illustrated by Figure 1.

The proportion of the labour force having a university degree was 5.4 per cent in Canada[11] in 1965 compared to 11.6 per cent in the United States[10]. Figure 2 shows that the higher average levels of education in the United States are the result of trends dating back several decades, with the trends to high education in Canada lagging those in the United States by 20 or 30 years. As of 7 years ago, the Bertram study[12] notes:

> "The conclusion respecting university attainment based on the 1961 Census is that the proportion of Canadian males in the youngest age group (25–34) in the male labour force who completed a university degree was 6 per cent, while in the United States the proportion of males in the population of the same age group was almost 15 per cent."

During the past 20 years Canadian enrolments, and investment in education, have been accelerating and the gap in rate of output of educated workers has begun to close (see Figure 2, taken from Bertram[12]). There will, of course, be a considerable time lag before these higher rates of output have any profound impact on the average educational level of the total labour force, relative to the United States. Thus, while the Economic Council has pointed out[13] that a

* For References indicated herein for Section 1, see *infra*, pp. 28–30.

higher total economic output should follow from the higher educational level, it will be some time before any economic growth attributable to that cause becomes very visible.

In the meantime large increases of investment in educational plant and operating costs are necessary to produce those rising numbers of educated workers. The table below shows that Canadian total expenditures on formal or institutional education, as a percentage of GNP (though not in dollars per capita), caught up to the United States about 1962 after many years at a lower level.

In the particular sector of "scientists and engineers" there is some more detailed information available, resulting largely from the efforts of the OECD in compiling statistics for international comparison. The numbers for Canada and the United States are plotted on Figure 1, and are shown as percentages of the total labour force in Figure 3. The OECD definition[15] of "scientists and engineers" includes mathematics, physical sciences, biology, geology, agriculture, and the usual categories of engineering, but excludes the health professions, architecture and the social sciences.

Table 1.— Total Expenditures on Formal Education[14,7,3]

Year	Millions of Dollars		Dollars per Capita		Educational Expenditures as Percentage of GNP	
	Can.	U.S.	Can.	U.S.	Can.	U.S.
1940	157	3,352	14	25	2.3	3.5
1950	464	9,335	34	62	2.6	3.5
1956	909	16,812	57	100	3.0	4.1
1958	1,235	21,120	72	121	3.8	4.8
1960	1,622	24,722	91	137	4.5	5.0
1962	2,281	29,430	123	158	5.6	5.5
1965	3,289	44,500	168	229	6.3	6.5

The OECD Survey Manual[15] explains (p. 19):

"Research work in the social sciences and humanities should be included within the scope of R. and D. activity. Most European countries do in fact use the term "science" to embrace the whole range of human knowledge, and not in the more restrictive "Anglo-Saxon" sense of natural sciences and technology. Surveys in some European countries have actually measured R and D activity on the basis of a definition including research in the social sciences. They have done so, however, only in the government sector, the higher education sector and other non-profit research institutes. The N.S.F. has also measured research in the social sciences separately in the government and non-profit sectors in the United States. But no country has so far successfully defined and measured research in the social sciences and humanities in *industry*. There is therefore still insufficient practical experience to provide a basis for standard definitions and conventions in this field.

"All those countries which have succeeded in measuring the *total* national resources devoted to R. and D. in *all* major sectors of the economy have done so on the basis of a definition which *excluded* research in the social sciences and humanities.

"Consequently, although these disciplines should certainly be included in principle within the total of R. and D. they should be separately measured and recorded. Otherwise it would not be possible to make any consistent time series or comparisons with surveys which have already been carried out. The OECD should regard it as a matter of urgency to bring together the available international experience in the measurement of research in the social sciences and humanities, and to conduct its own research on the outstanding problems. There are in particular, procedures for definition and measurement in such areas as work study, market research and operational research in the business enterprise sector. Otherwise there is some danger that the social sciences and humanities will become a kind of Cinderella and their importance overlooked."

Using that definition, it can be seen from Figure 3 that the employment of scientists and engineers as a percentage of the total labour force was 1.35 per cent for Canada in 1963 as compared to 1.8 per cent in the United States. A much greater difference is to be observed in the numbers of those scientists and engineers who are employed in R & D, shown in Figure 4. In 1965, 0.2 per cent of the total Canadian labour force consisted of scientists and engineers (full-time equivalent) engaged in R & D, compared to over three times that proportion, or 0.65 per cent in the United States.

While Figure 3 appears to show a slight widening of the scientist and engineer gap (as percentage of labour force) between Canada and the United States over the period from 1956 to 1963, Figure 2 gives hope that rising Canadian enrolments in higher education might by now be beginning to close the gap. The historical trend of rising output from the Canadian universities can be seen more clearly in Figure 5 for total first degrees and in Figure 6 for first degrees in natural sciences and engineering. However, a moment's reflection will make clear that, until the annual Canadian incremental input of degrees, from all sources, as a percentage of the labour force, equals or exceeds that of the United States, the "quality" of the latter's labour force will continue to draw away from the Canadian. Comparative figures for the output of natural scientists and engineers from the universities are shown in Table 2, suggesting that, as of 1963, Canada still had some way to go, at least in generating its own supply. Of course, a proper calculation has to be based on the actual input to the labour force, allowing for immigration, attrition, and upgrading outside of the formal educational system. Comparison of immigration figures for Canada and the United States indicates no change in those qualitative conclusions up to 1963, though striking increases in net professional immigration to Canada in the years since, amounting to about 40 per cent of the university output in 1965, indicate that parity of input might have been achieved in 1965. The data, however, are preliminary estimates and may not be sustained by subsequent data. Further, parity in 1965 was so dependent on a high proportion of immigration that its continuance is difficult to predict.

This brief review of the historical trends has set the stage for consideration of what trends will be most likely over the next ten years.

Table 2.—Output of First Degrees in Natural Sciences and Engineering Relative To Numbers of Scientists and Engineers in the Labour Force*

Year	Percentages	
	Canada	United States
1957	3.7	6.7
1959	4.2	7.3
1961	4.6	6.5
1963	4.8	6.5

* It may be worth pointing out also that the Canadian labour force is a lower proportion of the total population (36% in 1962) than the U.S. (40%).[3]

Projections to 1978 of the Numbers of Scientists and Engineers

The output of first degrees from Canadian universities and colleges has been projected to 1975-76 by Illing and Zsigmond for the Economic Council of Canada.[34] Their projection is shown in Figure 7, extended an additional three years to 1977-78 by simple extrapolation. The projection is based on population statistics and proportional enrolment trends for the relevant age groups.

An upward bulge in the curve from about 1964 to 1972 can be attributed to the postwar "baby boom", but by far the largest factor determining the slope of the curve is the rise in enrolment ratio, from 4.2 per cent of the 18-24 age group in 1951-52 to 10.1 per cent in 1965-66, projected to rise to 18.2 per cent by 1976-76 (for men and women, total, in undergraduate and graduate schools). Illing and Zsigmond assume that

> "increases in enrolment ratios will remain almost as high over the balance of the decade as they have been over the first half of the 1960s, and... they will tend to taper off during the first half of the 1970s."

The justification for the "tapering off" assumption is not made clear, but presumably derives from a belief that the Canadian catching-up process will slow down as United States ratios are approached. The United States full-time enrolment as a percentage of the 18-24 age group was 19.4 in 1965-66, projected to rise to 23.1 by 1975-76.[34]

Next it is necessary to examine the trends of subject-matter choice within the total first-degree projection. These are exhibited in Figure 8, in terms of the subject categories which have been used by the Dominion Bureau of Statistics. It may be noted that some remarkable shifts have been occurring over the past decade, notably steep downward (relative) shifts in Engineering, Medicine, and Other;* and less steep downward shifts in Commerce, Agriculture, and Architecture. These are complemented by steep upward shifts in Education, and Science; and a less steep but numerically large upward trend in Arts. Consequently, it has been necessary to rely to a considerable extent on intuition and aesthetic sense to project the trends into the future. About the only rule or principle used was that trends should not be subjected to any sharp reversals, in the absence of evidence. The reader is invited to try his own hand.

The results are generally similar to Mitchener's[35] but have the advantage of an additional four years' data.[31, 36] The more recent trends seem to favour a higher proportion of "Arts" and lower proportions of Engineering and Science by 1976-77 than were arrived at by Mitchener.

Of course, the trends could be considerably modified, or even reversed, by changes in Federal or provincial policies. Thus universal medicare could exert an upward pull on health sciences; or major engineering and development programs might reverse the downward trend in engineering graduations as a

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* "Other" is chiefly made up of Law, Theology, Social Work, Physical and Health Education, Household Science, Library Science, Journalism, Music, etc. The categories are those used by Mitchener[35].

proportion of the whole.* However, since most courses involved require a minimum of four years, any change in enrolment choices would show little effect on graduation ratios until four years later. Taking into account in addition the inevitable time lag between policy decisions made now, and any large-scale implementations or public visibility, it would seem that only influences already at work in the schools and the community are likely to have much effect on the projections except, say, for the last three or four years before 1978.

Interpreting the significance of the recent trends is rendered difficult by the fact that the subject categories used are outmoded. Thus "Arts" in the Canadian academic definition includes, besides the subjects generally called "humanities", such subjects as psychology, sociology, economics, geography, anthropology, mathematics, some general science, and here and there some Pure Science, in all of which people may graduate with the B.A. degree with various amounts of specialization. Mathematics, though small, appears to be one of the fastest growing components, to judge from some meagre data and from the United States trends (which are generally reflected sooner or later in the Canadian).

The Role of Women

The participation of women in higher education has been rising from 23 per cent of total bachelor-level graduations in 1955-56 to 34 per cent in 1966-57. Over half of the women (55 per cent in 1966-67) graduate in Arts, about 22 per cent in Education, and the remainder are distributed through Science, Nursing, Household Science, Library Science, Pharmacy, Physiotherapy, etc. It should come as no surprise, then, to find on closer examination of the data that the rising trends in proportion of graduates in Arts, and Education (Figure 8), can in the largest part be accounted for by the influx of women. As a percentage of total graduations, women baccalaureates in Arts rose from 11.6 in 1955-56 to 19 in 1966-67, while male baccalaureates increased their share more slowly from 27.4 per cent (but 25 per cent in 1960-61) to 29.9. Similarly, in Education, female graduations grew from 2.6 per cent in 1955-56 to 7.5 per cent in 1966-67 while male graduations, except for an intervening peak, grew from 5.4 per cent to 7.2 per cent. In Science, women graduations have also been growing steadily, but in this case only to keep step with the relatively rapid growth of the male graduations, which continue to outnumber the female by four or five to one.

Possibility of Preference Shifts from Physical Sciences to Social Sciences and Humanities

It is fairly often said nowadays that the younger generation is showing a profound disaffection with science, or engineering, or business, etc., and that

* *Note:* While medical and engineering outputs are declining *as a proportion of* the whole, their absolute numbers and numbers relative to total population are still increasing. Thus, the current substantial investments in increased medical training and research facilities are expected to increase medical graduations from about 40 per million population in 1965 to about 64 per million in 1975. Similarly, engineering graduations are projected in Fig. 8 to increase from about 114 per million population in 1965 to about 180 per million in 1975. Whether these numbers will be less than or more than sufficient to meet the needs is a separate question.

there is or shortly will be a substantial shift in enrolments away from science and engineering and into the Social Sciences, Arts, and Humanities. Since such a shift could throw our projections into disarray it is important to look for any evidence that is occurring.

The analysis in the previous sub-section made it clear that, up to 1966-67, the major shifts exhibited in Figure 8 toward Arts, and Education, were caused by the rising enrolment of women in higher education, and therefore reflect the traditional preferences of women, rather than any general change in philosophy or social attitudes. The decline in Engineering has been roughly compensated by a rise in Science, with the net effect that the graduations in Natural Sciences and Engineering were 16.1 per cent of total bachelor graduations in 1954-55, passed through a peak of 20 per cent about 1960, and have declined again since to 15.3 per cent in 1966-67. The curves as projected on Figure 8 predict a slower decline to about 14 per cent of total by 1978. This decline, along with the relative declines in Commerce, Medicine, Agriculture, Architecture, and Other, is complemented by a slow shift into the male component of Arts, amounting to about an added 0.5 per cent per year from 1960 to the present.

In view of the fact that Arts, in the Canadian definition, is a mixed bag, the significance of the above shift is still not clear. Detailed statistical data are available only for the Honours courses, which account for about 15 per cent of total bachelor-level degrees. Within the Honours courses, proportions of degrees granted among Sciences, Social Sciences, and Humanities are virtually constant up to 1964-65 (Figure 9), but then a clear increase in the proportion graduating in the Social Sciences becomes apparent in the most recent figures. This, however, tends to occur more at the expense of the Humanities than at the expense of the Sciences. Within the Sciences, there is apparent some shift in preferences toward the biological as against the physical sciences. If we look to the United States for possible hints of the future, we find the data more complete but the conclusions not much different. Table 3 shows some figures abstracted from a fuller report,[37] to show the breakdown of *total* bachelor and first professional degrees by field. A growth in the Social Sciences and Psychology is evident, rising from 14.4 per cent of the total in 1955-56 to 18.9 per cent in 1965-66, and projected to reach 22.8 per cent by 1975-76. However, this growth has not been and is not expected to be at the expense of the Natural Sciences and Engineering, which remain roughly at one quarter of all degrees at the bachelor level. The report[37] comments (p. 24):

> "In 1965–66, about one-fourth of all first level degrees... were awarded in the fields of study consisting of the natural sciences and related professions. The remaining three-fourths were awarded in the social sciences, humanities, and related professions. These proportions are expected to change little between 1955–56 and 1975–76."

A diagram similar to Figure 8, but with some differences in categories, was plotted from the United States projections (Figure 10). The Humanities, as distinct from the Social Sciences, are included in "Other", which is projected

Table 3.—Percentage Distribution of Bachelor's and First Professional Degrees in the United States

(abstracted from Ref. 37, pp. 29, 30)

Year	Total Number of Degrees	Total Natural Sciences	Mathematics and Statistics	Engineering	Physical Sciences	Biological Sciences	Agriculture and Forestry	Health Professions	Science, General Program	Total Social Sciences and Humanities	Fine Arts	Philosophy and Religion	English and Journalism	Foreign Languages	Psychology	Social Sciences	Education	Library Sciences	Social Work	Other
1955–56........	311,298	27.7	1.5	8.5	3.7	4.0	2.3	7.2	0.4	72.3	5.9	2.1	5.4	1.3	1.8	12.6	18.2	0.5	0.6	24.1
1965–66........	540,000	25.3	3.9	6.6	3.3	4.8	1.3	4.9	0.5	74.7	5.6	1.7	7.5	2.8	2.8	16.1	17.8	0.5	0.7	19.1
1975–76........	938,000	25.0	6.9	4.9	3.7	5.6	0.4	2.8	0.7	75.0	5.0	1.4	9.6	4.5	3.7	19.1	16.6	0.5	0.7	13.6

to decline slightly in proportion of the total. The rapidly rising importance of "Mathematics, Statistics and Computer Systems" should be noted.

Looking at *total* Canadian undergraduate *enrolments* in universities and colleges (Table 4) there is a slight decline in proportion of enrolments in Science and Engineering from 1960 to 1962, which could be correlated with the slight drop in proportion of Honours graduates in those fields from 1964 to 1966. However, the proportional enrolments have partially recovered and remained practically constant since, providing no basis for projecting a continuing decline in graduations. A still earlier indicator for projecting future trends could be found in a survey of enrolments and career intentions in the early undergraduate years, but such data are not available.

Table 4.—Canadian Full-Time Undergraduate Enrolment in Universities and Colleges[31,30,38]

Year	Total	Pure Science % of Total	Engineering and Applied Science % of Total	Total Science and Engineering %
1966–56	69,310	7.3	16.2	23.5
1960–61	107,339	9.1	13.6	22.7
1962–63	132,952	10.9	10.8	21.7
1964–65	164,441	12.9	9.3	22.2
1965–66	188,692	13.1	8.8	21.9
1966–67	212,953	13.4	8.7	22.1
1967–68	261,207	13.5	8.8	22.3

We can only conclude that, while there is evidence for shifts within the Sciences into Physical Sciences and Biological Sciences, at the expense of Engineering, there is no strong evidence for pronounced change in the total. There is a trend upwards in Social Sciences, but mostly at the expense of the Humanities. The patterns are similar in both Canada and the United States.

Projection of University Output of Scientists and Engineers

Pending further evidence, we therefore proceed on the basis of Figure 8. To allow for the graduates in Science and in Mathematics who appear with a B.A. degree under Arts, an examination was made of detailed figures obtained from the universities of Toronto, Edmonton, British Columbia, Carleton, McGill, Saskatchewan, Queen's, and McMaster. It appeared that, over the past ten years, the numbers graduating in such courses amounted to a roughly constant 20 per cent of those graduating in Science. The assumed proportion graduating in Science was therefore raised by a constant 20 per cent. To judge from the United States data (Figure 10) this correction may not allow fully for the rising importance of Mathematics in this age of computers, data processing, and statistical analysis, but is probably a reasonable working assumption until such time as better data can be compiled. Adding together Science, Engineering, and Agriculture we then have the results shown in Table 5. The total percentages were multiplied by the Economic Council projections for total first degrees to give the data in the last column.

Table 5.—Percentage of Total Bachelor's and First Professional Degrees

Year	Agric. %	Eng'g %	Science %	B.A. Science and Math (Est.) %	Total %	Total Number First Degrees (Ref. 6)	Total Number Natural Sciences, Maths, and Eng'g
1955–56						13,770	
1956–57						14,783	
1957–58						16,062	
1958–59						17,080	
1959–60						18,720	
1960–61						20,240	
1961–62						23,102	
1962–63						25,221	
1963–64						29,084	6,259
1964–65						33,497	6,700
1965–66	1.7	5.8	9.4	1.9	18.8	38,470	7,240
1966–67	1.6	5.5	9.8	1.9	18.8	43,843	8,230
1967–68	1.5	5.2	9.9	2.0	18.6	50,800	9,450
1968–69	1.4	5.0	10.0	2.0	18.4	58,300	10,760
1969–70	1.3	4.8	10.1	2.0	18.2	66,400	12,100
1970–71	1.2	4.6	10.2	2.0	18.0	74,200	13,400
1971–72	1.15	4.5	10.3	2.1	18.0	81,800	14,800
1972–73	1.1	4.3	10.4	2.1	17.9	89,000	16,000
1973–74	1.05	4.2	10.4	2.1	17.7	95,700	17,000
1974–75	1.0	4.0	10.5	2.1	17.6	101,900	17,900
1975–76	0.98	3.9	10.5	2.1	17.5	106,600	18,600
1976–77	0.95	3.8	10.6	2.1	17.4	(110,000)*	19,100
1977–78	0.93	3.6	10.6	2.2	17.4	(115,000)*	20,000

* Numbers extrapolated beyond Economic Council projection.

Projected Input to the Labour Force

The above data for output from the universities will be augmented or reduced by the following factors to give the net input to the scientific and engineering labour force.

(a) *Continuation of Studies*: A proportion between 10 per cent and 30 per cent of the bachelor graduating class will go on to graduate studies (as high as 74 per cent for physics baccalaureates in the United States in 1966-67, according to a survey by the American Institute of Physics[39]). Their entrance to the full-time labour force will therefore be delayed by periods of one to six years or so. On the other hand, most graduate students are employed at least part-time as instructors, lecturers, and research assistants, and draw on funding as part of the R & D work force. As a reasonable and convenient assumption, we take the latter interpretation and assume that graduates enter the labour force at the bachelor level.

(b) *Current, or Actual Labour Force as Against Potential Labour Force:* Not all people trained in a certain discipline necessarily enter employment which requires such training, for the following reasons: (i) over-supply for the existing demand, (ii) drop-out due to unsuitability or change of interest. In the first case, some of the over-supply emigrate, some shift to employment in related areas, still within science and engineering and some accept employment where their specialized education goes unexploited—a form of technological underemployment. However, the aim of this exercise clearly is to project the *probable* supply of qualified scientists and engineers, *assuming normal employment*, rather than to predict the elasticity of that supply in the event of under-demand, and therefore the effects of supply-demand mismatch will be ignored, except as they appear under other headings such as emigration and drop-out. In the second category, there are always some graduates who decide they are really unsuited for the work, or develop interests which lead them into quite unrelated careers. A distinction is sometimes attempted between those who are actively "doing" Science and Engineering, and those who are working in fields such as research management, technical sales, etc., where their training is a valuable asset or prerequisite. The latter interpretation is probably closer to the established practice, and is surely more realistic for judging optimum utilization in relation to supply. By drop-outs then we clearly mean those who find no position within the Science and Engineering technostructure, and who move to careers for which their specialized education is at best marginally useful. Women, particularly, show a relatively high drop-out rate. Analyses for the United States by the National Science Foundation[7] show that, by two years after bachelor graduation, 20 per cent of the women were employed as housewives, and about 3 per cent in secretarial, office, and clerical jobs. Figures for male graduates, depending on the field of specialization, and on where one draws the boundary of the science and engineering technostructure, amounted to 5 per cent or 10 per cent of the total group. Indeed, a certain attrition of this type is as it should be and should be encouraged. No one could claim that every bachelor graduate in Science or Engineering is worth his salt. A certain amount of pruning is proper and necessary to maintain quality. The problem is to make a reasonable estimate of its magnitude. We propose the somewhat arbitrary figure of 10 per cent of the graduating class to be pruned out or to drop out within five years, and a negligible percentage thereafter. This is based on the data for United States males, since women still constitute only a small fraction of the Canadian science and engineering graduation. For simplicity the 10 per cent is removed in one lump from the graduating class. The small error which this introduces will in any case act to compensate the small error from ignoring the delayed entry to the labour force of some (full-time equivalent) fraction of the graduate student population.

(c) *Normal Attrition*: Besides the above effects of transfer from one specialized occupation to another, the labour force as a whole suffers a steady attrition due to deaths and retirements. Actuarial statistics show attrition rates for men ranging from about 1 per cent to more than 3 per cent, depending on the age composition of the particular occupation.[40]

> "For women, the rate ranges from 3 to 5%. Occupations which have recently experienced rapid growth and therefore have a high proportion of young persons have retirement and death rates at the lower end of the scale. In the illustrative projections. the retirement and death rate for engineers was estimated at 1.5% per year for the decade."

For the science and engineering work force only the rates for males need be considered. Because of Canada's young and more rapidly growing labour force, and a probable catching-up effect in science and technology, it is likely that the attrition rate should be assumed lower than the American but 1.5 per cent will be at least a conservative estimate.

(d) *Immigration and Emigration*: Data for immigration, emigration, and net immigration* to Canada of scientists and engineers over the last five years are shown in Table 6. A steep growth of net immigration is evident, to number 3006 in 1966, a number about 40 per cent of the output of scientists and engineers from Canadian universities in the year 1965-66. The number of immigrants, if it stays as large, can clearly swamp the effects of any small shifts in Canadian academic patterns. The current high level is undoubtedly due in large part to deteriorating conditions in the United Kingdom, and to internal turmoil, budget cuts, draft policies, etc. in the United States. Those conditions might be expected to continue for at least the next three years, but then might be followed by a rising demand in the United States, owing to shortages created by the effect of recently instituted draft policies. Over the next three years there may be particularly high immigration to Canada from the United Kingdom because of the way that recent changes in the United States immigration laws have, inadvertently, closed the doors to British immigrants until the accumulated backlog of quotas from other countries has been admitted. Canadian emigration to the United States may be blocked by the same effect. Further, the volume of emigration of Canadians to the United States will depend greatly on policies and conditions in Canada. All these factors introduce serious fluctuations and unpredictabilities into the business of predicting the Canadian professional manpower supply. For this first projection we propose the assumptions shown in Table 7, with the proviso that the situation needs to be kept under review, and revised as events transpire. We have assumed net immigration at 30 per

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* The number of emigrants to the United States who subsequently return to Canada has never been properly counted. Estimates for the number of emigrants of all occupations who return range from one in eight to as high as seven in eight (K. V. Pankhurst, "Migration between Canada and the United States", *Annals of the American Academy of Political and Social Science*, September 1966). The recruitment campaign "Operation Retrieval" seeks to reinforce the flow. Thus the true net immigration figures could be significantly higher than shown here.

Table 6.—Immigration, Emigration, and Net Immigration of Scientists and Engineers to Canada*

Item	1962	1963	1964	1965	1966
Total emigration to United States of Scientists and Engineers with last residence in Canada	1,060	1,171	1,089	1,191	1,105
Scientists	237	274	293	289	246
Engineers	823	897	796	902	859
Total immigration to Canada of Scientists and Engineers	1,377	1,568	2,032	3,110	4,111
Scientists	410	370	556	856	1,101
Engineers	967	1,198	1,476	2,254	3,010
Net immigration of Scientists and Engineers	317	397	943	1,919	3,006

* *Sources of data*: See References 41, 42 and 43.

cent of graduations** for the three years 1967-69, dropping to 20 per cent from 1970 on, as Canadian graduations grow and, hopefully, conditions in Canada and other countries stabilize. These assumptions can easily be subject to large error, but probably err on the conservative side, i.e., probably underestimate the potential supply.

(e) *Upgrading*: It has been the practice, particularly in engineering, for substantial numbers of technical workers to gain recognition as being of professional grade, without possession of a formal degree. This may come about by passing examinations set by professional societies, or via the judgment of a man's managers and supervisors in industry, or simply in a man's own estimation. As an example of the latter, a survey of persons classified in scientific and technical occupations in the 1960 U.S. census, carried out by the Bureau of the Census for the National Science Foundation (Ref. 7, p. 86), showed 45.5 per cent of engineers in the civilian labour force as having no academic degree at all. By contrast, among the considerably smaller number of *scientists*, as reported in the National Register of Scientific and Technical Personnel,[44] there were very few without a degree. The National Register approach was by questionnaire, through the professional societies and virtually defined the bachelor degree, or higher, as the criterion of professional qualification, thus not surprisingly showed a mere 1 per cent or 2 per cent of scientists as having less than a bachelor's degree. A third source of United States statistics is the Bureau of Labor Statistics, who poll employers regarding what their employees are "working as". The extent of discrepancy among these approaches is illustrated by the figures below (from Ref. 44, p. 3).

** The justification for relating assumed immigration numbers to university graduations is grounded in the common expectation that university output bears some relation to the rate at which new opportunities are expanding in the society. However, when the home-grown supply is growing at a very steep rate, one might doubt that demand will keep pace, and then one might expect rather to see a growing substitution of domestic for foreign supply. The assumed drop from 30% to 20% attempts to allow for this effect, but must be admitted to be a guess.

Table 7.—Net Immigration of Scientists and Engineers as a Percentage of University Graduations

Year	Net immigration	Graduations at First-Degree Level in Academic Year Ending in Year Shown	Net Immigration As Per Cent of Graduations
1962	317	5,154	6.2
1963	397	5,393	7.4
1964	943	6,259	15
1965	1,919	6,700	29
1966	3,006	7,140	42
1967			(30)*
1968			(30)*
1959			(30)*
1970			(20)*
.			.
.			.
.			.
.			.
1978			.

* Assumed.

Table 8.—Estimates of Number of Scientists in United States Labour Force

Source of Registrations	Number	Classification
U.S. National Register (1964)	224,000	Natural and selected Social Scientists
U.S. Bureau of Labor Statistics (1963)	361,000	Natural Scientists only
U.S. Bureau of the Census (1960)	275,000	Natural and Social Scientists

The second and third figures only hint at what the size of the upgrading phenomenon might be, but give no basis for estimation. The National Science Foundation has studies under way aimed at understanding and reconciling the discrepancies between these different methods of gathering the statistics. A recent inquiry elicited from the National Science Foundation the estimate that out of a current 1.5 million individuals in the United States labour force classified as "scientists and engineers", approximately 300,000 to 375,000 have not earned at least a four-year college degree. The Canadian statistics show a similar pattern and a similar haziness of definition. A survey of employers by the Department of Labour[45] in 1962 showed that, of personnel employed as engineers, 4 per cent had no degree but had attained professional certification, and 9.3 per cent had no degree and no certification. Of those employed as natural scientists, the corresponding figures were 1.2 per cent and 2 per cent. An approximate annual rate of upgrading is obtainable for one year (1959) from an earlier report of the Department of Labour.[46] The total number of employees upgraded to professional status during 1959, other than by obtaining a university degree, was 473 among the employers surveyed. This number was 23 per cent of the number of new university graduates hired. These figures, sparse though they are, suggest that upgrading is an important component of the annual input to the science and engineering labour force. What assumptions should be made for purposes of projection? Will the upgrading phenomenon become less or more important in the future? To argue for its becoming less important we have the fact that university entrance is coming to be open to all of requisite ability; the financial barrier is declining. On the other hand, there are two social trends that make it likely to become *more* important: (1) greatly increasing numbers of graduates from technological institutes, who have been launched part way, (2) increasing prevalence of *continuing* education, in-plant courses, etc., probably with less emphasis on formal degrees. It must also be recognized, of course, that upgrading is subject to large fluctuation, being highest in times of high demand and short supply. Taking these various factors into account, we propose as a first working assumption an annual upgrading component equal to 20 per cent of the supply of new graduates. Linking it to the university graduations rather than to the total labour force will give it a somewhat rising importance along with the general rising recognition of the value of higher education. We feel that both these assumptions are conservative, in underestimating if anything the potential supply of science and engineering manpower due to the upgrading component.

(f) *Foreign Students*: A number of the graduates from Canadian universities are foreign students, who do not enter the Canadian labour force or, if they do, appear as "immigration". An inspection of past records suggests that 5 per cent of each (total) graduating class is a reasonable approximation to allow for this effect at the present time.

To summarize, we make the following provisional assumptions about the future annual input to the science and engineering work force:

Drop-out: 10 per cent of graduating class (subtracted).

Attrition due to deaths and retirements: 1.5 per cent of total S & E work force (subtracted).

Net immigration: 30 per cent of graduating class to 1969, declining to 20 per cent thereafter, as shown in Table 6 (added).

Upgrading: 20 percent of graduating class (added).

Foreign Students: 5 per cent of graduating class (subtracted).

The last official estimate of the Canadian science and engineering work force was in 1963 in figures supplied to the OECD.[6] The number given was 92,600, which included architects. Subtracting the estimated number of architects, for consistency with definitions, gives a starting point of 89,760. The computation of projected numbers from that point on is shown in Table 9.

Errors and Surprises

Every projection is an attempt to predict the future and is therefore subject to errors from misinterpretation of present trends, and errors from unexpected new developments, or surprises, in the course of events. The present unsettled state of world affairs, with the Vietnam war, racial unrest in the United States, monetary gold crisis, threatened setback to world trade, Federal-provincial constitutional tension in Canada, and so on, leaves the door wide open to predicting any number of surprises and calamities that would affect trends in manpower supply and demand—possibly resulting at some time in widespread unemployment. Current economic uncertainties, plus a program of strictures on government spending, have been creating through 1967 and 1968 a situation in Canada of slowdown in hiring of new graduates by industry, while at the same time government agencies are prevented by austerity rulings from taking them on instead. The surplus supply is further augmented by high immigration, and a somewhat lowered emigration (of the young) to the United States for fear of being drafted into the military. The effect of this potential over-supply may be to provide an opportunity to the educational systems to upgrade the quality

Table 9.—Projection of Canadian S & E Work Force to 1978*

(1) Year	(2) University Graduations, Scientists and Engineers, Bachelor Level	(3) Drop-out −10% of (2)	(4) Foreign Students −5% of (2)	(5) Upgrading +20% of (2)	(6) Net Immi-gration +30% of (2) to 1969 then 20%	(7) Attrition −1.5% of (8) previous year	(8) Total S & E Work Force (rounded)
	+			+	+		
1963....							89,760
1964....	6,260	626	313	1,252	943*	1,350	95,900
1965....	6,700	670	335	1,340	1,919*	1,440	104,000
1966....	7,240	724	362	1,448	3,006*	1,570	113,000
1967....	8,230	823	412	1,646	2,480	1,700	123,000
1968....	9,450	945	472	1,890	2,840	1,840	134,000
1969....	10,760	1,076	538	2,152	3,220	2,000	146,000
1970....	12,100	1,210	605	2,420	2,420	2,180	159,000
1971....	13,400	1,340	670	2,680	2,680	2,380	174,000
1972....	14,800	1,480	740	2,960	2,960	2,590	190,000
1973....	16,000	1,600	800	3,200	3,200	2,840	207,000
1974....	17,000	1,700	850	3,400	3,400	3,100	225,000
1975....	17,900	1,790	895	3,580	3,580	3,370	244,000
1976....	18,600	1,860	930	3,720	3,720	3,650	263,000
1977....	19,100	1,910	955	3,820	3,820	3,940	283,000
1978....	20,000	2,000	1,000	4,000	4,000	4,240	304,000

* Statistical data.

of their teaching staffs, turning out the less qualified onto the labour market. The improvement in standards of teaching could be a highly desirable result, but would not be likely to reduce the consequent future demand for higher education. As a general rule, the more highly educated and trained component of the labour force may suffer from *under* employment, i.e., less than full use of their abilities, but they will rarely be unemployed; the less educated will be displaced downward and it is the least educated who will end up in the ranks of the unemployed, even when their talents are adequate for the jobs from which they are displaced. A related argument will affect enrolment choices in universities. While the effect of a severe economic recession might be to disillusion scientists and engineers with their career prospects in a less promising new world, a switchover to humanities would not be likely to offer better prospects; the edge would tend to lie with graduates in the technical specialties (which would include economics, mathematics, sociology, etc.). Increased enjoyment of fine arts, history, and philosophy is more likely in times of secure economic prospects.

In former times an economic recession would have meant a large-scale drop in university enrolments as individual incomes dropped. In this day of belief in equal opportunity that effect is less likely and, while expenditure on facilities and staff might be kept to a minimum, it could even be that young people would be *encouraged* to pursue post-secondary education, since otherwise they would simply swell the ranks of surplus labour.

On the above arguments, even a major economic setback might affect the projected trends only indirectly. On the other hand, prosperity, and major new national ventures to put technology to work in the public interest (e.g. in transportation, communication, urban design, regional development) might excite the public interest and generate a renewed enthusiasm for the pursuits of Science and Engineering. Hard times might cause a drop in the "upgrading component", which might be offset by an increased enrolment in "practical" courses. Good times might bring an increase in upgrading but also a rise in preference for Arts or leisure-oriented courses. Good or bad economic conditions in Canada relative to elsewhere could cause immigration to rise or drop accordingly; extraordinarily high immigration rates would bring pressure (and opportunity) to put those talents to work. Progress toward higher productivity might bring increased leisure, and higher attrition rates, due to early retirements (or early retirements might be enforced as a result of over-supply). The multiplicity of such factors means that it is impossible to estimate a "probable error" for the projection in any usual meaning of the term. The projection can at best be taken as "a most reasonable guess". A mitigating factor is that errors in the assumed annual inputs will be reduced in their effect on the final labour force figure by the stabilizing effect of the initial stock. The doubling time of the total science and engineering work force as projected is eight or nine years. Thus a 20 per cent error in the assumed net input each year would, if maintained, accumulate to give a 10 per cent error in the total after eight or nine years.

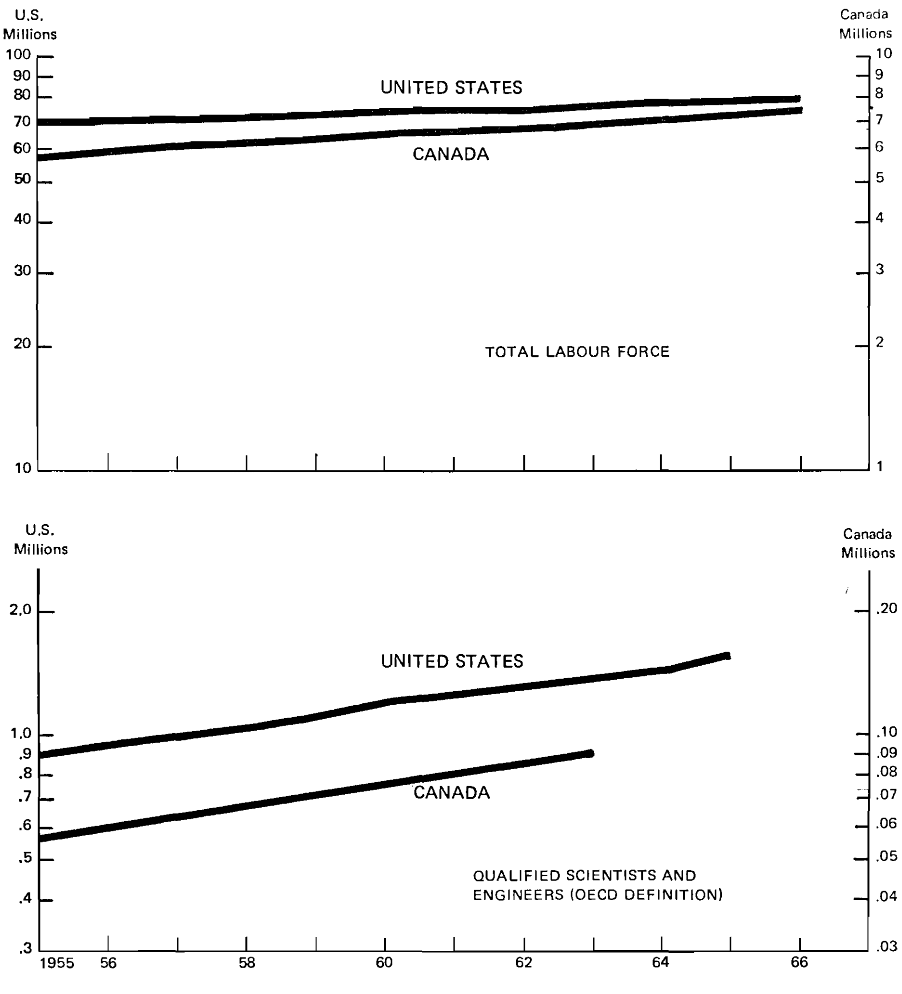
A variation of that order of magnitude could follow, for example, from a drop of net immigration to zero for most of the period projected.

On the basis of demographic data, such as the number of the population in the 18-20 age group, we are on fairly safe ground, since even the 1978 graduates are already in the school system. Some margin for error exists in the assumed participation of that group in higher education, which is assumed to rise from 10.1 per cent in 1965-66 to 18.2 per cent in 1975-76, but the rise is an extrapolation of a fairly stable long-term trend, and is further supported by the experience of United States trends, where the participation rate was already 19.4 per cent in 1965-66,

The largest errors are therefore likely to stem from the exogeneous factors—immigration, upgrading, and attrition—the factors most sensitive to political and economic conditions. Also, while the trend projections of inputs might be accurate, the absolute numbers projected for the scientific and engineering work force depend on the accuracy of the data in a single base year (1963). It is to be hoped that current work of the Department of Manpower and Immigration and the Dominion Bureau of Statistics will before long provide additional and more recent check points.

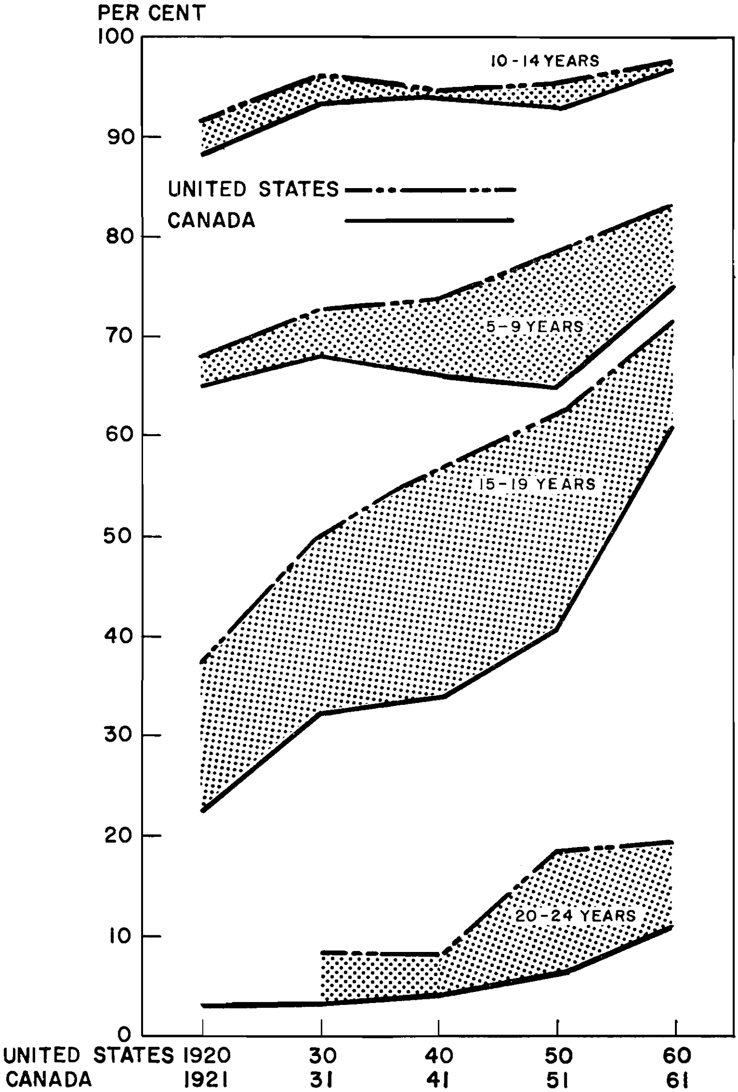
The sum up, this projection is a first exercise in forecasting the probable supply of engineering and scientific manpower in Canada over the next ten years. We hope it will be a useful input to considerations of science policy. Like any projection, however, it must be regarded as provisional, subject to confirmation and revision as the basic data improve and as time progresses.

Figure 1.—Labour Force in Canada and United States



Note: Labour Force includes Armed Forces. References 1–8.

Figure 2.—Male Enrolment in School as a Percentage of Total Male Population in Age Group, Canada and United States



Source: G. W. Bertram, "The Contribution of Education to Economic Growth", Economic Council of Canada Staff Study No. 12 (June, 1966).

Figure 3.—Employment of Natural Scientists and Engineers as a Percentage of the Total Labour Force

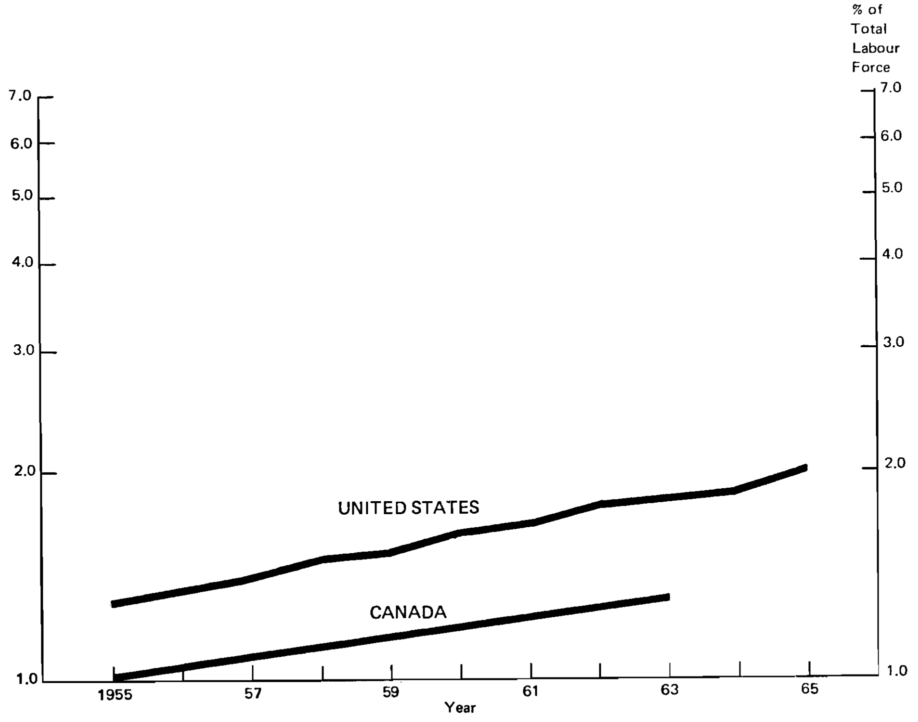
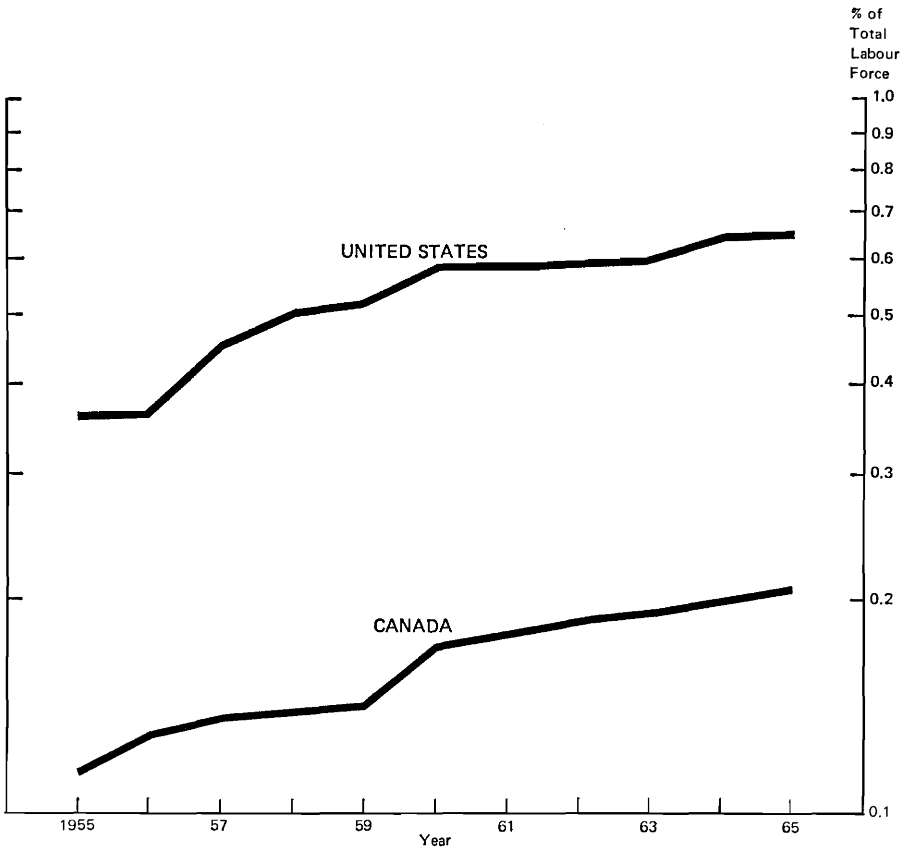
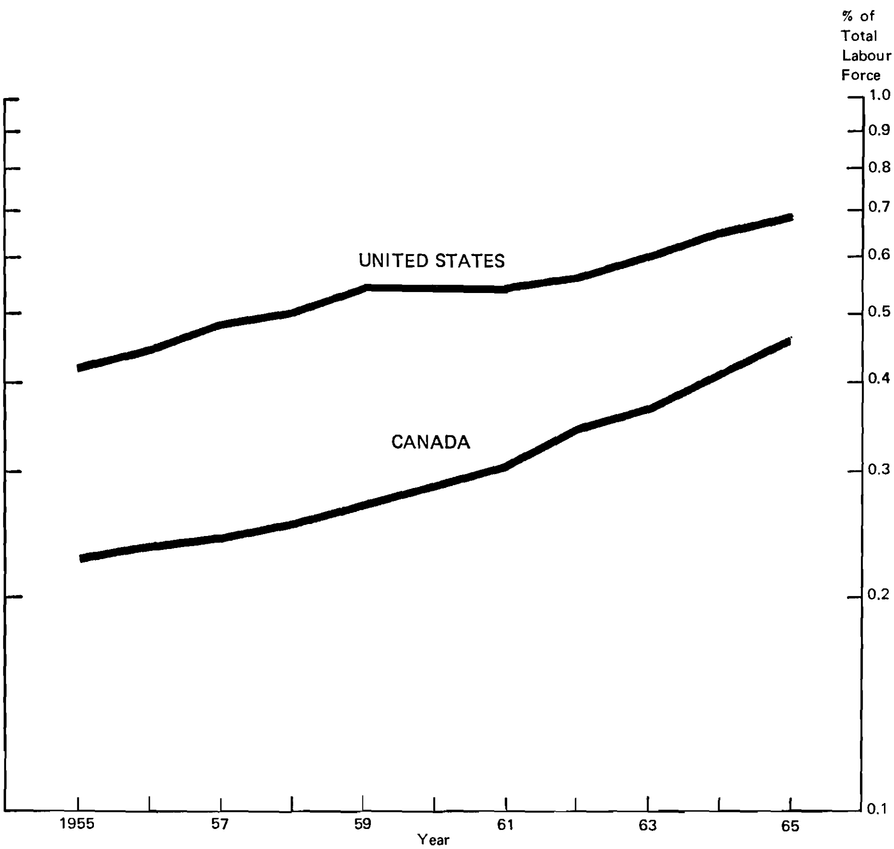


Figure 4.—Employment of Natural Scientists and Engineers in R & D as a Percentage of Total Labour Force



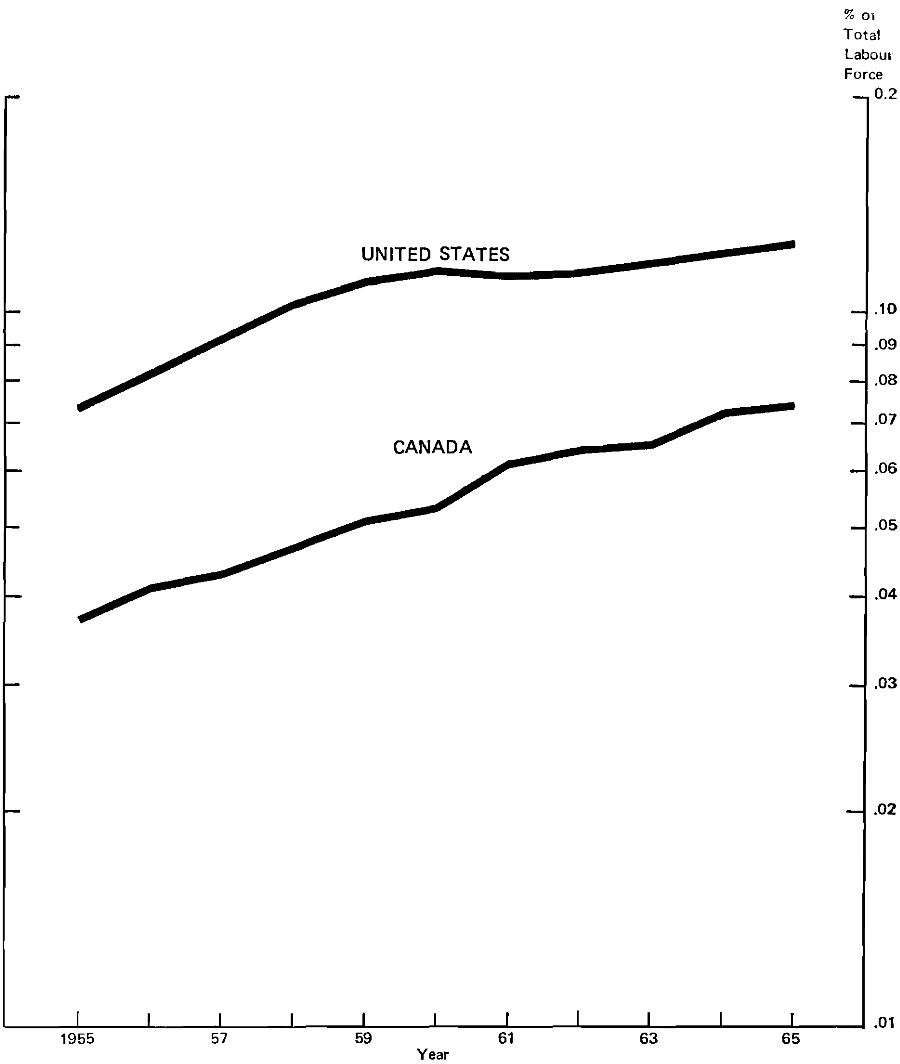
Source: See References 16–28.

Figure 5.—Total Output of First Degrees* as a Percentage of Total Labour Force (Including Health Professions) Academic Year 1959-60 = 1960



* "First Degrees" refers to bachelor and first professional degrees.
Source: References 7, 29–32.

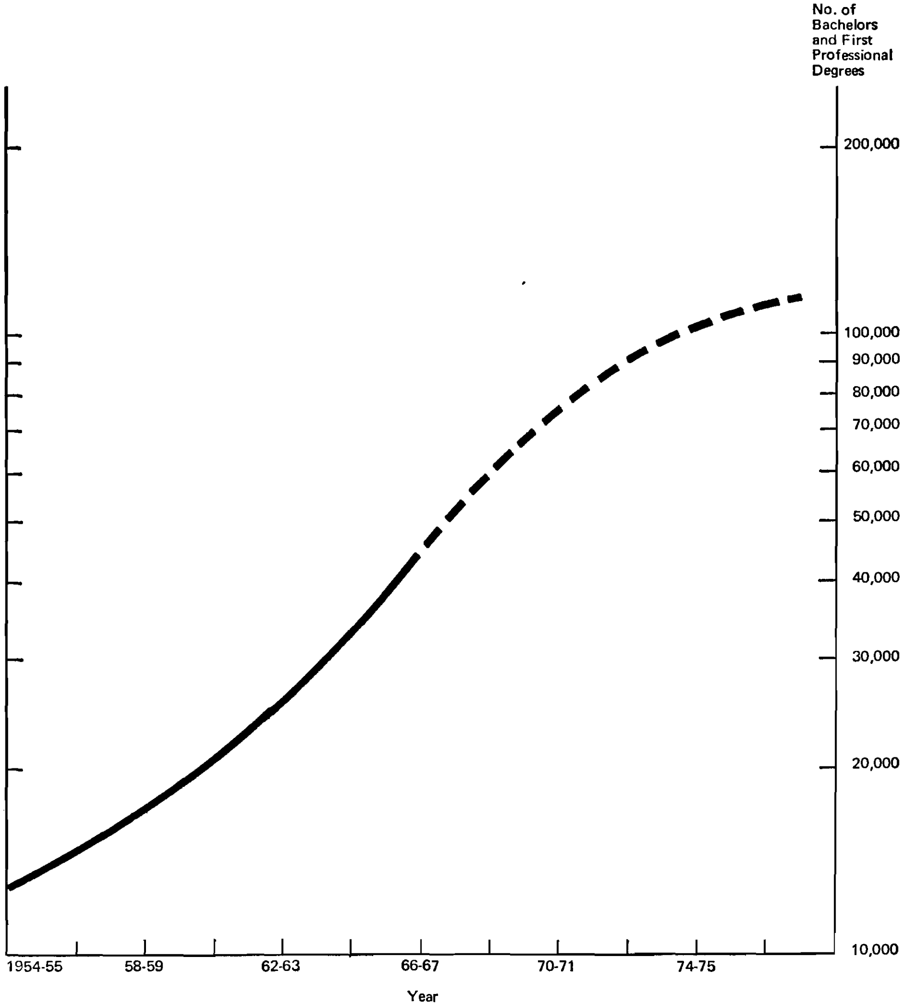
Figure 6.—Output of First Degrees in Natural Sciences and Engineering as a Percentage of Total Labour Force (Excluding Health Professions, Agriculture, and Architecture) Academic Year 1959-60 = 1960



Note: Canadian figures exclude Mathematics, and some Science graduates with the B.A. degree, who were recorded as graduating under "Arts".

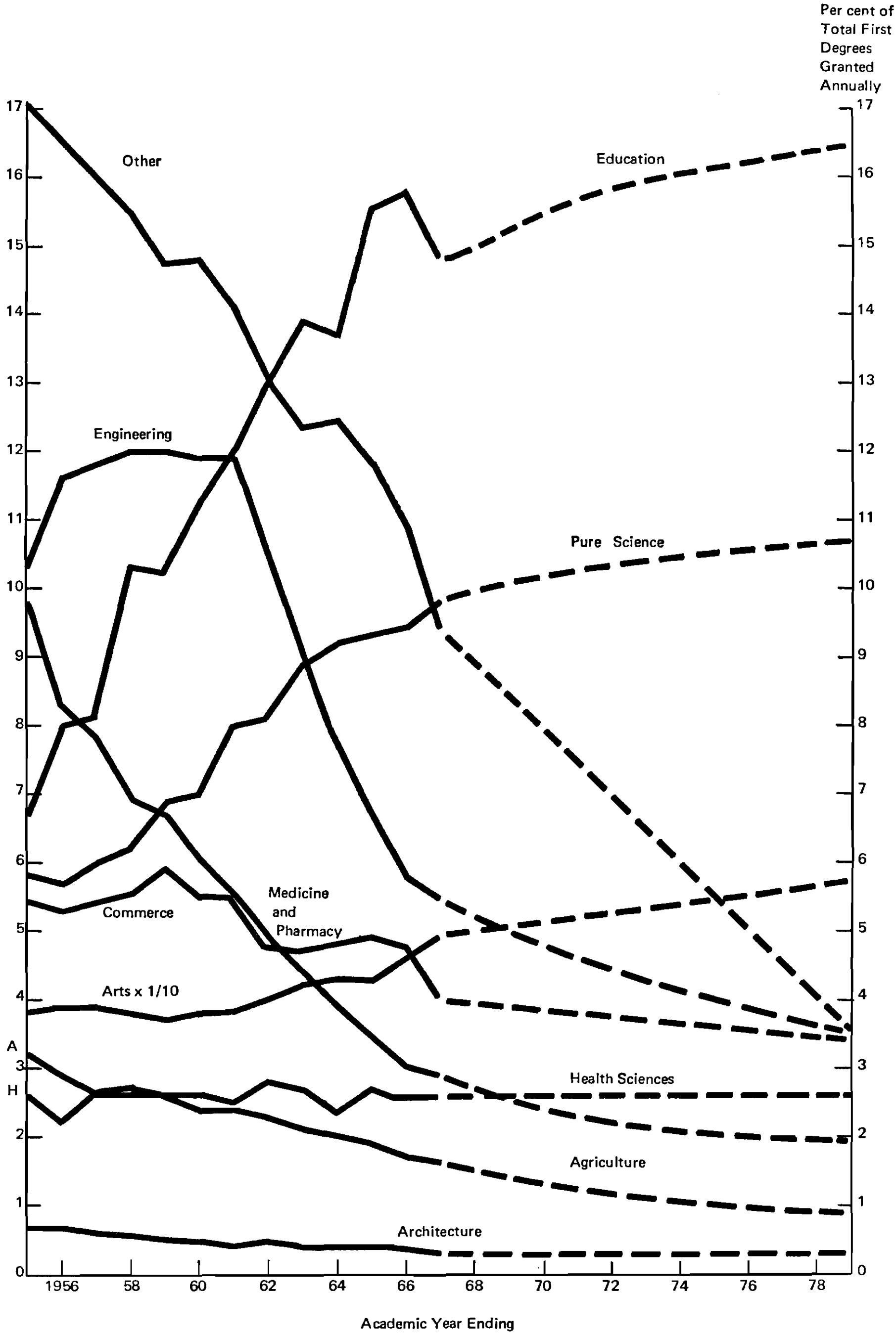
Source: References 7, 29, 31–33.

Figure 7.—Projection of Annual Output of Total Bachelors and First Professional Degrees



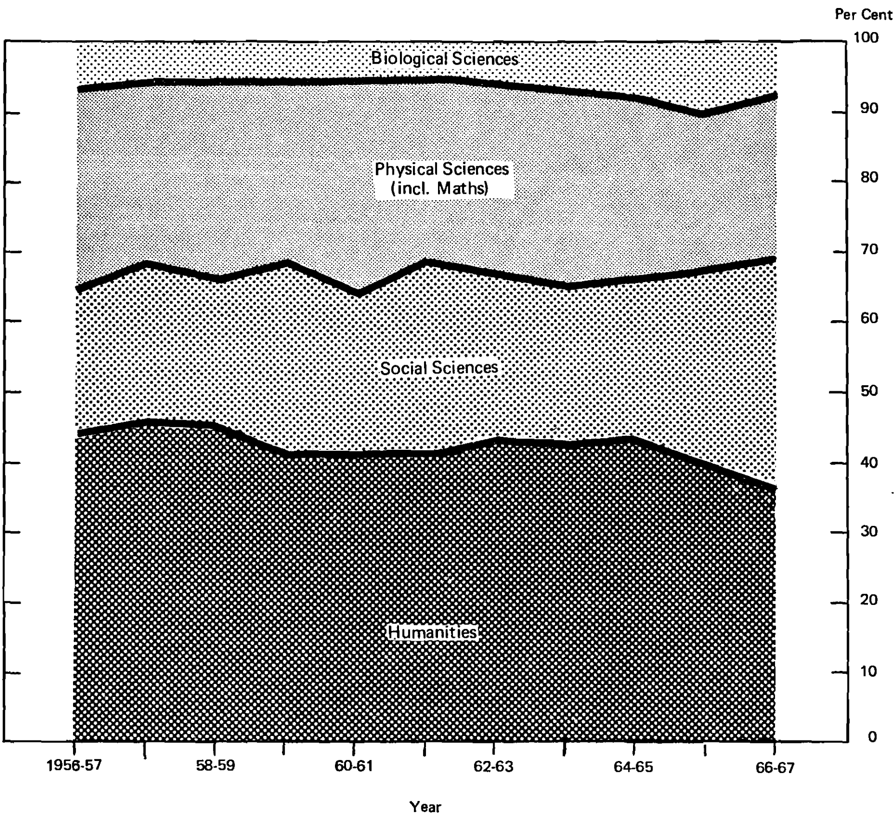
Source: W. M. Illing, Z. E. Zsigmond, "Enrolment in Schools and Universities 1951–52 to 1975–76". Staff Study No. 20, Economic Council of Canada, October 1967.

Figure 8.—Breakdown of First Degrees Among Specialties: Canada — Actual and Projected



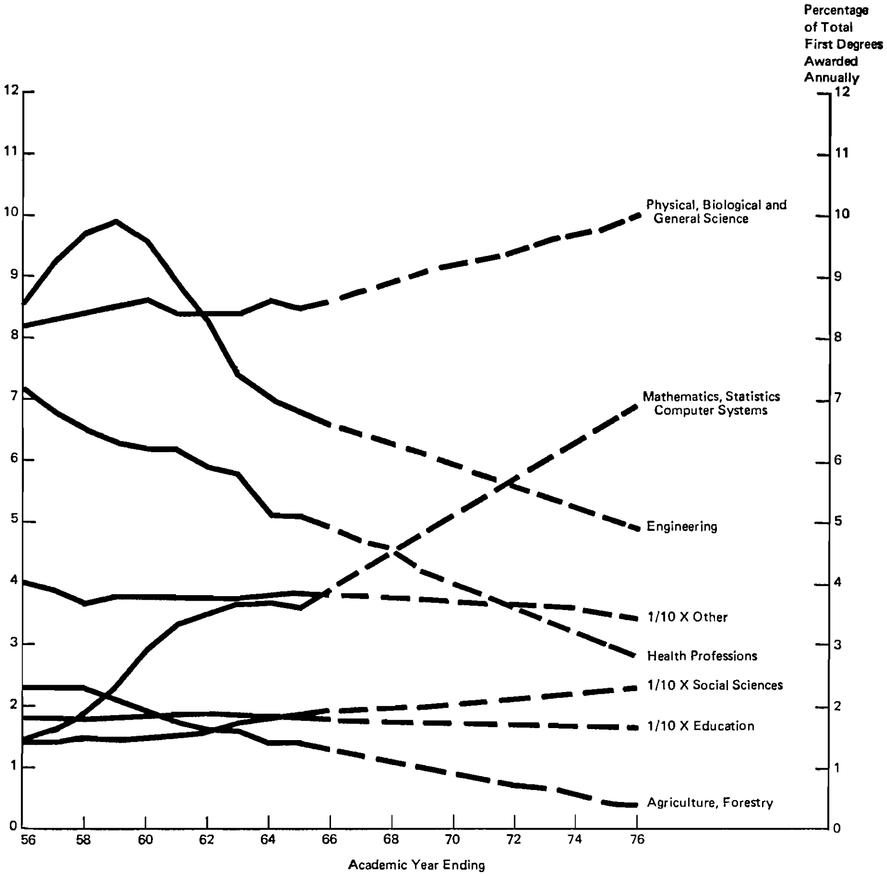
Source: References 33, 35, 36.

Figure 9.—Breakdown of Honours Bachelor Degrees Granted by Canadian Universities into General Areas



Source: References 31, 33.

Figure 10.—Breakdown of Bachelor and First Professional Degrees: U.S. — Actual and Projected



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15 OECD, *Proposed Standard Practice for Surveys of Research and Development*, DAS/PD/62.47, (3rd revision), Paris.

16 "Natural Scientists", following the OECD definition, does not include agricultural scientists.

17 The 1955, 1956, 1957 figures for the U.S. were estimated from figures for expenditure (Reference [7]) divided by an average cost per professional (full-time equivalent).

18 The U.S. figures for 1958, 1961, 1965 were obtained from the National Science Foundation "National Patterns of R & D Resources, Funds and Manpower in the U.S., 1953-68", NSF 1967-7, Washington, 1967.

19 The U.S. figure for 1959 was computed from data in Reference [6].

20 The U.S. figure for 1960 was obtained from National Science Foundation, "Profile of Manpower in Science and Technology", NSF 1963-23, Washington, 1963.

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26 The Canadian figures for 1960, 1962 were estimated from Reference [6] and (i) "Employment and Earnings in the Scientific and Technical Professions 1959-1962", Report No. 14, Economics and Research Branch, Department of Labour, Ottawa, 1963; (ii) OECD, "Training of and Demand for High-Level Scientific and Technical Personnel in Canada", Paris, 1966.

27 The Canadian figure for 1963 was obtained from Reference [23].

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Section 2

THE R&D INFLATION-SOPHISTICATION FACTOR

Introduction

The R&D inflation-sophistication factor can be defined as the mean percentage increase over a particular time period in the annual costs (in current, rather than constant, monetary terms) of research and development per qualified scientist and engineer (QSE) engaged full-time equivalent (FTE)[1] in R & D. The R & D expenditures being considered could refer to the gross expenditures on R & D (G.E.R.D.) of a country, the R & D expenditures of a sector of the economy, or of an area of research (e.g., space or defence). In this paper, the R & D expenditures alluded to in all cases include both current and capital (unless otherwise stated), and exclude social science research expenditures.

The term "inflation-sophistication factor" is a complex *escalator* factor which combines a number of influences difficult if not impossible to separate. The following components can be noted qualitatively:

(*a*) *Rise in prices of goods and services used in the R & D sector.* It is related to the general rise in price indexes (inflation) in the economy, but differs in rate from, for example, the consumer price index, since the R & D sector has its own peculiar mix (which includes the salaries of scientists, engineers, and technicians, as well as the prices of equipment with high R & D content, such as computers, etc.).

(*b*) *Rise in the cost of research because of the increasing complexity of science.* The belief is that "the simple experiments have been done". To make an advance of given "importance" requires increasingly sophisticated and elegant instrumentation. Clearly this term is subject to wide fluctuations from one field of science to another and along the time scale of particular developments or breakthroughs. Also, there is nothing to say how the balance between output and input is to be arbitrated—that is to say, it would theoretically be as possible for society to choose a constant rate of input of expenditures and a declining scientific output, as for it to choose a "constant output" and a rising level of expenditures. Furthermore, even the basic belief may be questioned, in view of the fact that some types of experiment that formerly were difficult and time-consuming can now be performed with great ease. In other words, there is a contest between rising complexity (difficulty) and rising experimental and theoretical power (productivity). Who is able to say which is winning?

[1] Unless otherwise indicated, the increases in R & D costs per QSE will be calculated on a full-time equivalent basis in the remainder of this paper.

(c) *Change in capital/labour ratio.* Since the factor being discussed is in terms of costs *per scientist or engineer*, it will reflect trends in choices based on the relative productivity of equipment as against manpower, while the trends referred to above relate to the absolute or total costs of a given scientific or technological advance. Considering the context in which such choices are made, whether they be for a chart recorder, an automatic chromatograph, or an on-line computer, they are usually cost-saving decisions, aimed at obtaining a given output for less money. Nevertheless, choices trending in favour of equipment act to increase the inflation-sophistication factor as defined here.

For the purpose for which this factor is being developed here, namely, to relate projected manpower or staffing trends or plans to projections of total R & D costs or expenditure, there is, pragmatically speaking, no need to evaluate separately the various components. It will be treated as a single factor, albeit with a complex name, and a general macroscopic average will be sought, based on past experience and studies, to use as a reasonable basis for projections over the next decade in Canada or the United States. The results of several studies will be reviewed briefly below, and some additional data will be considered.

Relevant Data

(a) "A Proposed Cost-of-Research Index", [E. A. Johnson and H. S. Milton, Staff Paper ORD-SP-142 (revised), Operations Research Office, the Johns Hopkins University, September, 1960]. The authors investigated the experience of seventeen individual research organizations over the period 1950-59 and found that the annual R & D costs[2] per QSE increased at the rate of 6.9 per cent per annum. The authors point out that the consumer's price index increased at the rate of 2.5 per cent per annum over the same time period. The seventeen organizations were located in industry, universities, government and the private non-profit sector.

(b) "Cost-of-Research Index, 1920-1965", [H. S. Milton, AD-629-700, Research Analysis Corporation, McLean, Virginia, March, 1966]. This study is essentially an up-dated version of the above-mentioned publication. The conclusions are similar; the annual increases in R & D costs[2] per QSE averaged close to 6 per cent (6.1%) between 1950 and 1965. By five-year periods, the average increases were about 6.8 per cent for 1950-55, 7.8 per cent for 1955-60 and 4.0 per cent for 1960-65. The author also noted that the average annual increases in technical man-year costs for development-oriented research organizations and for theory-oriented research organizations differed rather little over the period from 1950 to 1965 (6.4 per cent per annum and 5.9 per cent per annum respectively).

(c) "The Cost of Basic Research Effort: Air Force Experience, 1954-1964", [E. D. Brunner, RM-4250-PR, the Rand Corporation, February 1965].

[2] In the two papers described in (a) and (b), the capital expenditures are accounted for indirectly through annual depreciation charges.

This study was done for the U.S. Air Force Office of Aerospace Research by the Rand Corporation. The purpose of the study was to determine the costs of accomplishing basic research projects financed by AFOAR's Office of Scientific Research during the fiscal years 1954-1964. The study found that between 1954 and 1964 the R & D costs per scientific man-month rose by 6.5 per cent per annum.

(d) "The Cost of Basic Scientific Research in Europe: Department of Defense Experience, 1956-1966", [E. D. Brunner, RM-5275-PR, the Rand Corporation, April 1967]. The Rand Corporation did this study for the Department of Defense agencies which sponsor basic research in European countries through all types of research agreements (grants, contracts, cost-sharing and non-cost-sharing agreements). Many types of European research organizations were considered in the study—universities, industrial concerns, non-profit institutions, international organizations, and individuals (some with, some without institutional connections). The author found that the total cost per scientific man-month for all types of research agreements between the Department of Defense agencies and European research organizations increased at an average of 6.1 per cent per annum between 1957-58 and 1965-66.

(e) "The Sophistication Factor in Science Expenditures", [A. V. Cohen and L. N. Ivins, Scientific Secretariat, Council for Scientific Policy, Science Policy Studies No. 1, Department of Education and Science, U.K., 1967]. This study was an attempt to determine the sophistication factor, as opposed to the combined inflation-sophistication factor, for the R & D performed over an 8-11 year period at nine Ministry of Technology stations (formerly belonging to the Department of Scientific and Industrial Research), the National Institute for Medical Research at Mill Hill, the Rothamsted Experimental Station, the Atomic Energy Research Establishment at Harwell, the Central Veterinary Laboratory of the Ministry of Agriculture, Fisheries and Food at Weybridge, the Chemistry Department at one university, and the Geology and Zoology Departments at another university. The authors concluded that

> for an institution viewed as a whole, with a constant complement of young scientists, typical weighted growth rates per scientist might be two to five per cent in constant-value terms per annum, though in other circumstances, variations outside these limits are possible. There may be an important exception to this generalization. Research grants to universities in some cases involve the purchase of a much higher proportion of permanent equipment, often in a rapidly developing field. The appropriate rate of sophistication in these circumstances might then be significantly higher than those quoted here, though this must depend on the relative proportion of the grant on equipment and, of course, on the nature of the subject that is supported.

Table 1 shows the combined inflation-sophistication factors for the various research organizations over the defined time periods.

Table 1.—The Inflation-Sophistication Factor in Certain Research Organizations in the United Kingdom

Research Organizations	Time period	Mean annual increase in R & D costs per QSE over given time period*
1) Nine ex-DS 1R Stations	1954–55 to 1964–65	6.0 ± 0.5%
2) National Institute for Medical Research	1957–58 to 1965–66	8.6 ± 1.3%
3) Rothamsted Experimental Station	1956–57 to 1964–65	9.6 ± 0.8%
4) Atomic Energy Research Establishment, Harwell	1956–57 to 1965–66	4.3 ± 0.6%
5) Ministry of Agriculture, Fisheries and Food, Central Veterinary Laboratory, Weybridge	1958 to 1965	11.2 ± 4.7%

* These mean annual increases are in current cost terms and so represent inflation-sophistication factors rather than sophistication factors.

(f) "The Increasing Cost of Research; A Preliminary Study", [L. R. Thiesmeyer, Pulp and Paper Research Institute of Canada, June 1964]. The author investigated the annual increase in R & D costs per professional scientist and engineers in 12 pulp and paper companies in Canada, as well as 15 companies in various other Canadian industries. The average annual increase in R & D costs per QSE for the pulp and paper companies was 6.2 per cent and for the 15 companies in other industries it was 6.6 per cent per annum. The time spans considered by the 27 companies ranged from 2 to 17 years, averaging a little over six years.

The authors of the present Section undertook a look at the past trends of the annual changes in the overall cost of R & D per QSE in R & D activities in the United States in the period between 1954 and 1965. The results of this study are shown in Figure 11 and Table 2, and they indicate an average overall increase of 5.9 per cent per annum (the R & D inflation-sophistication factor).

Evaluation of the Canadian experience with the rising costs of R & D per QSE engaged in R & D is rendered difficult by the perturbations introduced by the demise of the Arrow program, by the various new industrial incentive programs, and by the "austerity" program of the early 1960s, as well as by the lack of good R & D manpower and expenditure data before the late 1950s or early 1960s. The available information for government in-house R & D and/or industrial R & D, which for the above reasons should be treated very cautiously, is shown in Figure 12. For the government in-house R & D activities the average annual increase in R & D costs per QSE (non-FTE) between 1959 and 1965 was 5.0 per cent. But during the latter part of the period (1963 to 1965), the R & D costs per QSE (FTE) rose at 11.3 per cent per annum.

Figure 11.—U.S. R & D Costs per Qualified Scientist and Engineer over a Twelve-Year Period

$$\left(\frac{\text{G.E.R.D.}}{\text{R \& D Q.S.E.}}\right)$$

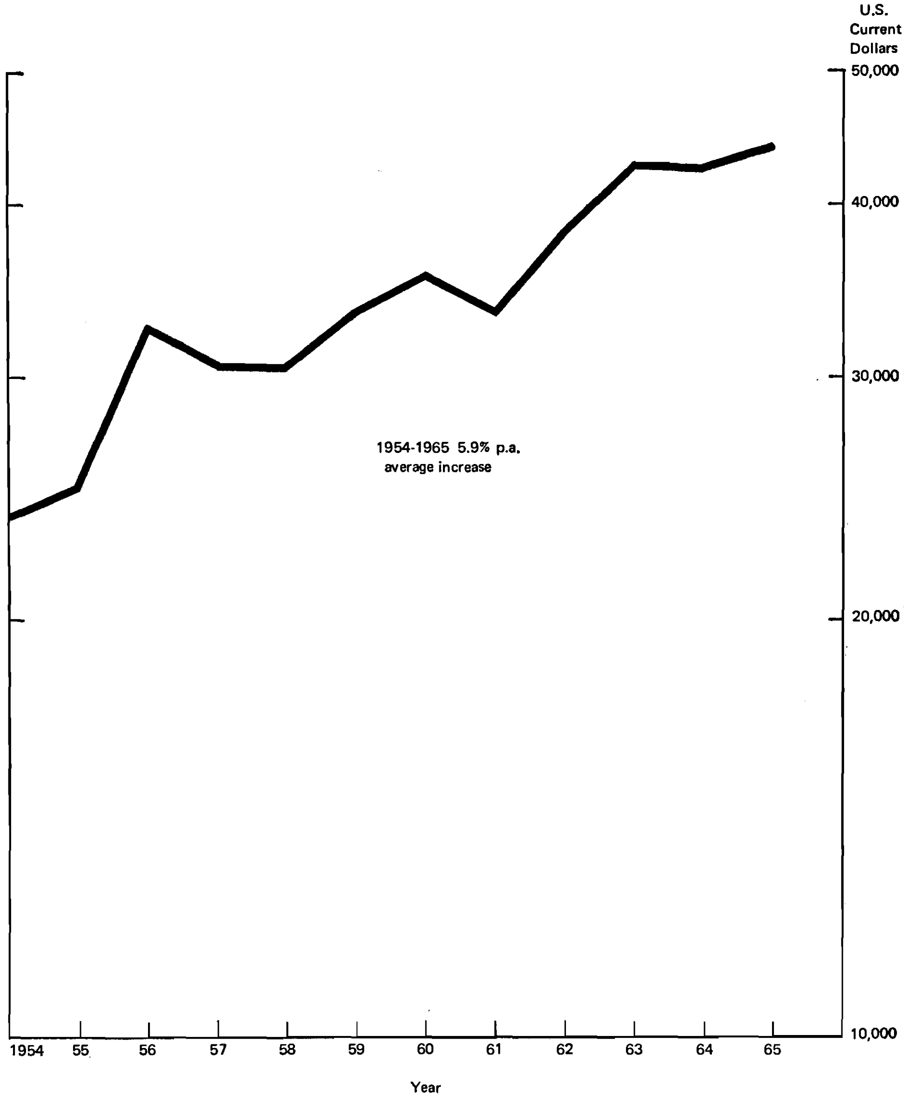
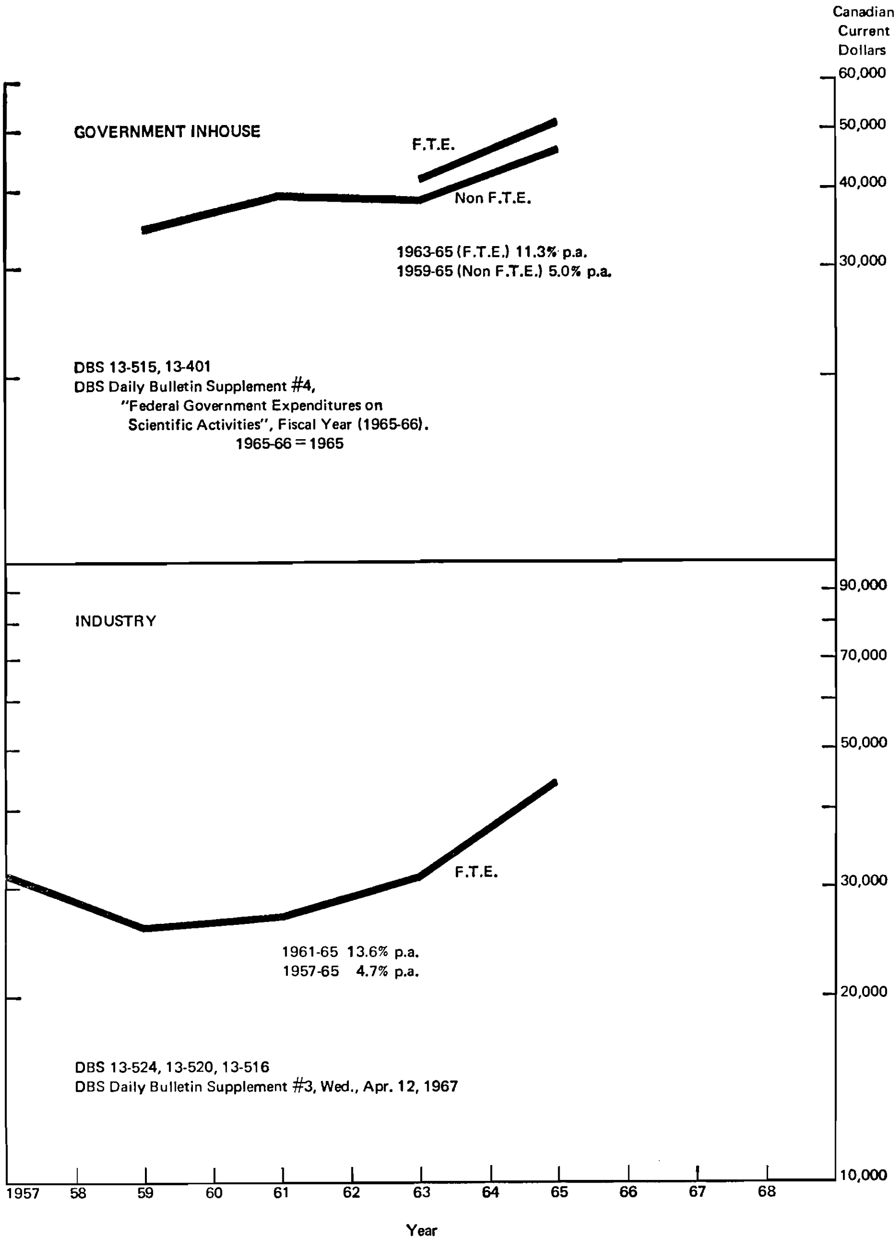


Figure 12.—R & D Costs per Q.S.E.: Canadian Experience



In industry, the average annual increase in R & D costs per QSE between 1957 and 1965 was 4.7 per cent, but between 1961 and 1965 the average increase was 13.6 per cent per annum.

Internally consistent information is difficult to obtain with respect to the costs of the R & D performed in the Canadian universities and the manpower involved in R & D activities. Figure 13 shows both the best estimate of R & D expenditures (direct plus indirect) in Canadian universities between 1957 and 1966, and a reasonable estimate of the QSE involved in R & D activities (medical researchers excluded) between 1955 and 1966. The two sets of data are not entirely comparable in an absolute sense, but the relative rates of increase between 1957 and 1966 have some significance (24.8 per cent and 19.1 per cent per annum, respectively). The difference between these growth rates is accounted for by a term growing at 4.8 per cent per annum, that may be taken as a rough measure of the R & D inflation-sophistication factor experienced by the Canadian universities.

Table 2.—United States G.E.R.D. and the Number of Qualified Scientists and Engineers Engaged in R & D

Year	A) U.S. G.E.R.D. (millions U.S. current dollars)	B) Number of QSE Engaged in R & D	A/B x 10^6 (rounded)
1954	5,660[1]	237,000[4]	23,900
1955	6,200[1]	248,000[5]	25,000
1956	8,370[1]	256,000[5]	32,700
1957	9,810[1]	321,000[5]	30,600
1958	10,810[1]	356,000[4]	30,400
1959	12,430[1]	372,640[6]	33,400
1960	13,620[1]	384,000[5]	35,500
1961	14,380[1]	429,600[4]	33,500
1962	16,650[2]	435,600[7]	38,200
1963	19,258[2]	450,000[8]	42,800
1964	21,075[3]	496,500[3]	42,400
1965	22,179[2]	503,600[4]	44,000

[1] National Science Foundation (NSF 65–11), *Reviews of Data on Science Resources*, Vol. I, No. 4, May 1965,

[2] "U.S. R & D Expenditures in 1967", a report from the Socio-Economic Section, Columbus Laboratories. Battelle Memorial Institute.

[3] "The Overall Level and Structure of R & D Efforts in OECD Member Countries", International Statistical Year for Research and Development, OECD, Paris, 1967, U.S. 1963–64= 1964.

[4] National Science Foundation (NSF 67–7), "National Patterns of R & D Resources 1953–1968", p. 9.

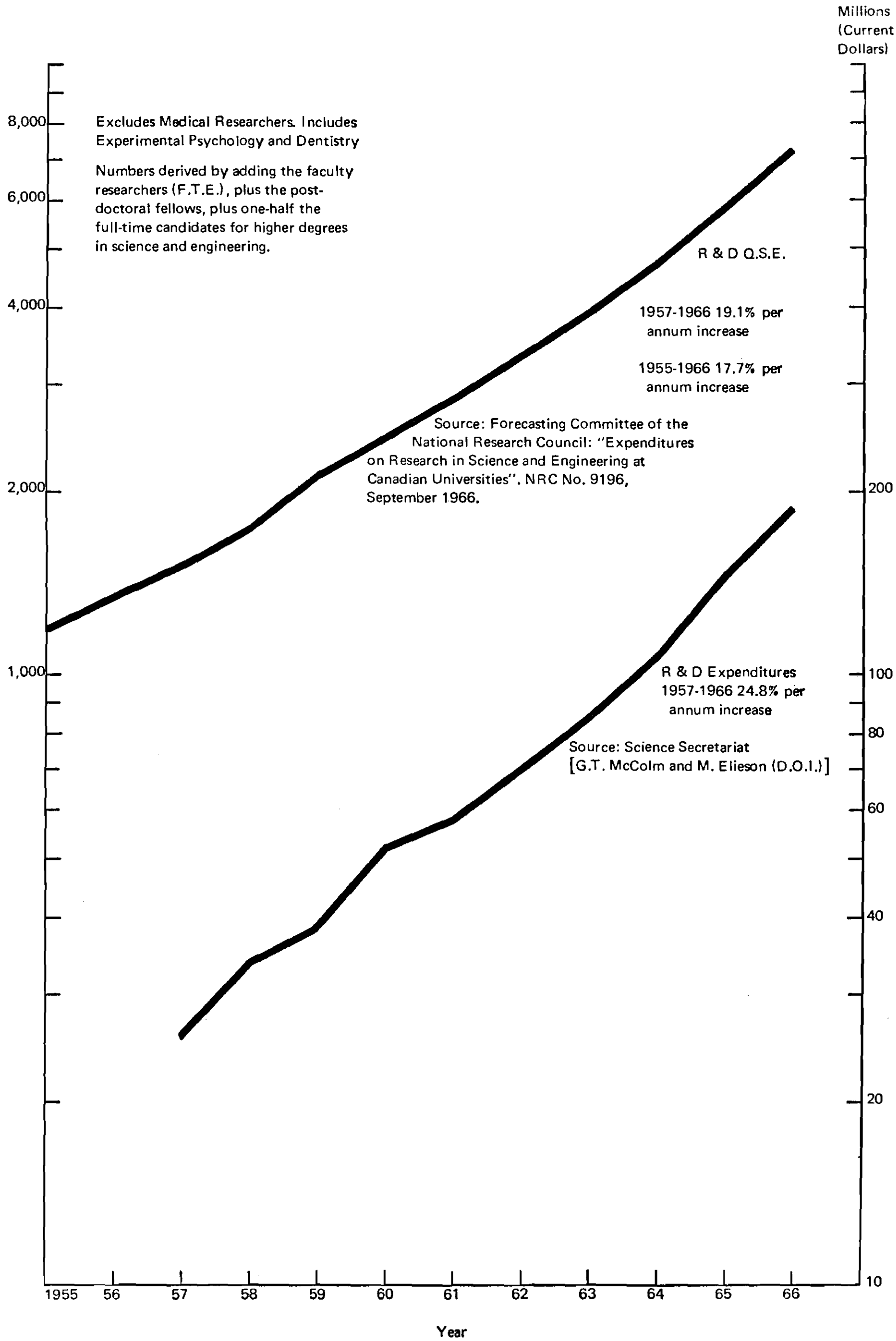
[5] Science Secretariat estimate.

[6] "Resources of Scientific and Technical Personnel in the OECD Area", pp. 174, 227.

[7] "The R & D Effort in Western Euope, North America and the Soviet Union", C. Freeman and A. Young, OECD, 1965, p. 72 (excluding medical personnel).

[8] Estimate, based on "Towards Better Utilization of Scientific and Engineering Talent", Report of the Committee on the Utilization of Scientific and Engineering Manpower, p. 8, and on "Scientific and Technical Manpower Resources", NSF 64–28, p. 14.

Figure 13.—R & D Expenditures and Q.S.E. Engaged in R & D in Canadian Universities and Colleges



Range of Deviation

Although the average figures for the inflation-sophistication factor are rather remarkably consistent, there is a considerable range of deviation when the scene is examined in more detail. This is shown particularly well by the United Kingdom study.

That there are wide variations should not be surprising, when it is recognized that the total field of research and development is in constant growth. There are bound to be flurries of activity and investment as one group or another is established, gets a new idea, or moves to catch up with others, and there will be low spots where a field lies dormant, is phased out, or withers away. These differences are reflected in the wide range of absolute cost per professional in different industries, as shown by some figures compiled by NASA.[3] The average annual cost per R & D QSE in the space program (in-house and contracts) was 45 per cent higher than the national average[4] during the fiscal years 1960 to 1964. On the other hand, the average annual R & D cost per QSE in the United States industrial sub-sector classified as "fabricated metal products" was 48 per cent lower than the national average over the same time period, and the cost in the sub-sector "professional and scientific instruments" was 25 per cent lower than the national average.[5] These figures can be taken as indicative only, since some figures in the NASA table clearly suffered from misinterpretation of definitions (one figure for total cost amounted to less than one person's reasonable annual salary).

There are also pronounced differences between countries. Attempts by the OECD to compare levels of R & D effort in various countries[6] led to the concept of a "research exchange rate", different from the official monetary exchange rate. Comparisons of gross R & D expenditure per QSE[7] at official exchange rates showed a range of 1:5 between the lowest (Japan) and the highest (U.S.).

The above figures of average annual cost per research professional suggest wide scope for variations in the rate of rise of costs (the inflation-sophistication factor). Forces which will tend to bring about a convergence of cost levels are: the competitive nature of R & D, the internationalism of science, the mobility of scientific personnel, and the diffusion of knowledge and techniques from one discipline to another. The ultimate rate of rise of costs will tend to be set by the leaders, or pacesetters. In that sense the inflation-sophistication factor may be arbitrary, or subject to policy but, once it is established by the pacesetter, the other competitors in the game have little choice.

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[3] Compiled by NASA for the Subcommittee on Employment and Manpower of the Committee on Labor and Public Welfare, U.S. Senate, Vol. 2 of "Selected Readings in Employment and Manpower", 88th Congress, 2nd Session, Committee Print 1964, Part II, pp. 663, 668.

[4] Executive Office of the President, ***The Budget in Brief, 1968***, Bureau of the Budget, 24 January 1967, p. 66.

[5] NSF 66–28.

[6] C. Freeman, A. Young, "The Research and Development Effort in Western Europe, North America, and the Soviet Union", OEDC, Paris, 1965.

[7] "The Overall Level and Structure of R & D Efforts in OECD Member Countries". OECD, Paris, 1967.

In particular, where an international boundary is highly permeable to the immigration of people and ideas, as is that between Canada and the United States, one can only assume that any differences in cost patterns of R & D cannot remain large for long. At the present time, the existence of fairly high salary differentials for scientists and engineers between Canada and the United States suggests that, provided Canadian conditions for R & D recover from the transient perturbations of the last 10 years,* the inflation-sophistication factor for Canada may well be higher than normal for some years until the gap is closed.

Before suggesting an appropriate working figure for Canada, two further points should be considered. Are there appreciable differences in cost per man between basic research, applied research, and development; and are there large differences between disciplines as, for example, between physical sciences, biological sciences, and social sciences. In other words, how sensitive might projected costs be to a possibly shifting mix of emphasis?

At the macroscopic level, Table 3 compares the present division between basic research, applied research, and development for the United States and Canada. The much greater emphasis on *development* in the United States is apparent. Yet, in 1965, the overall R & D costs per QSE were $44,000 (U.S. dollars, Table 2) in the United States and $45,500 (Canadian dollars)[8] in Canada. Figures for industrial laboratories in Canada, where the emphasis is on applied research and development, are currently more often than not below the cited figure but, on the other hand, costs in the United States on major space and

* and provided that the present phase of tightening research budgets in the U.S. is temporary.

[8] Science Secretariat estimate; from estimates of G.E.R.D. by G. T. McColm (Science Secretariat) and M. Elieson (DOI), and R & D Manpower (FTE) estimates by D.B.S. (*see* D. W. Henderson, R. W. Jackson and B. W. K. Leung, "Gross Expenditures on R & D in Canada Projected to 1978" *infra*, Section 3, Table 1).

Table 3.—Distribution of R & D Expenditures by Orientation

R & D	United States[1] (1964)	Canada[2] (1965)
Basic research	12.4%	22.4%
Applied research	22.1	40.6
Development	65.5	37.0
Total	100.0%	100.0%

[1] "The Overall Level and Structure of R & D Efforts in OECD Member Countries", OECD, Paris, 1967.

[2] "Statistical Data on Industrial Research and Development in Canada", DOI presentation to the Science Council of Canada, March 17, 1967. The breakdown refers to current R & D expenditures, while the U.S. breakdown includes current and capital. The assumption here is that the Canadian capital R & D expenditures would be distributed in approximately the same pattern as the current expenditures. This is a reasonable assumption, but even if all the capital R & D expenditures were incurred in development work, the U.S. effort would still be more development-oriented than the Canadian effort (65.5% vs 52%).

defence R & D projects tend to be higher than the average. Milton, whose work was reported above, found only a small difference in inflation-sophistication factor between development-oriented and theory-oriented organizations. These figures regrettably are rather inconclusive, but do not support the notion that any pronounced difference in overall inflation-sophistication factor is likely to result from new departures in Canadian R & D policy.

Data is sparse for social science research, but the tentative conclusions are similar. Contract consulting organizations in the United States working in such fields as economic development, urban studies, defence strategic studies, and so on, quote comparable rates to organizations doing laboratory work in the "hard" sciences. One reason for this is suggested by Table 4, which shows the breakdown in costs per QSE in the United Kingdom. It appears that equipment and stores represent a fairly small proportion of the total overhead costs. Social scientists require similar libraries, information services, office accommodation, supporting personnel, typists, etc. Their salaries are becoming comparable, they are coming to make at least as much use of computers, and

Table 4.—Breakdown of Costs per Professional Researcher in Selected Laboratories in the United Kingdom[1]

Laboratory	Year	Breakdown				Total
1) Nine ex D.S.I.R. stations	1964–65	Salaries and wages 53.7%	Accommodations and maintenance 27.7%	Minor and capital equipment 17.6%		100%
2) Rothamsted Experimental station	1964–65	Salaries and wages 70.7%	Accommodations, services and maintenance 17.7%	Equipment 7.8%	Misc. 2.8%	100%
3) Atomic Energy Research Establishment, Harwell	1964–65	Salaries and wages 50.8%	Building and maintenance 18.0%	Major equipment 17.0%	Stores etc. 14.2%	100%
4) National Institute of Medical Research	1964–65	Salaries and wages 75.0%	Accommodations and services 6.8%	Equipment 18.2%		100%

[1] "The Sophistication Factor in Science Expenditure", A. V. Cohen and L. N. Ivins, Scientific Secretariat, Council for Science Policy, Department of Education and Science, Science Policy.

they may have special additional expenses for survey, travel, and interview work. Thus, while every field or discipline will have its expensive special features, such as accelerators in high energy physics, primate laboratories in biology, Antarctic expeditions in meteorology or geology, a national census for social science, there does not seem to be firm ground for assuming that the costs per research professional in the social sciences will necessarily be much lower, or will rise at any slower rate, than the costs for research in the physical and biological sciences. At least the differences are not likely to be large enough to affect seriously the projections at the gross or macroscopic level.

Choice of a Provisional Inflation-Sophistication Factor for Canada

In the light of the above considerations, we suggest that an R & D inflation-sophistication factor of 6.0 per cent per annum would be a resaonable figure for use in projecting total Canadian R & D expenditures in current dollar terms over the next few years—under the conditions of a 2 per cent per annum increase of the implicit price index of the GNP. The latter, while not an exact measure of the R & D price index, should serve as an indicator of whether general conditions of price inflation in the economy are similar to those during the base period. The implicit price index rose at a mean rate of 2.7 per cent per annum for Canada and 2.1 per cent for the United States between 1949 and 1965, and 1.9 per cent for Canada and 1.4 per cent for the United States over the more recent period from 1960 to 1965.[9] Considering the present relatively low level of R & D activity in Canada, and generally expressed expectations that the level should be raised, we believe that the above suggested inflation-sophistication factor is if anything likely to prove conservative.

[9] Economic Council of Canada, *Third Annual Review*, November 1966, p. 92.

Section 3

GROSS EXPENDITURES ON R & D IN CANADA PROJECTED TO 1978

Summary

This Section presents an exercise in the projection of Canadian total expenditures on research and development over the decade to 1978. A set of plausible gross envelopes of national expenditure is related to a projected growth of the scientific and engineering work force, developed in Section 1 of this volume. Some reasonable assumptions are made by which to arrive at illustrative breakdowns of expenditure by sector in which the work is performed, and by source of funds. The work is not intended as a prescription for policy, but simply as a first experiment towards a computational model which may help to make clear the interrelatedness of science policy decisions affecting expenditure, manpower, education, and employment.

Introduction

A projection of expected total Canadian expenditures on research and development over the next decade could be attempted by simple extrapolation of past trends, or it could be derived from a consideration of principal policy goals with an attempt to forecast what proportion of the national income the society might choose to allocate to the pursuit of those goals. Neither approach would be satisfactory, at this time, the first because the history of Canada's R & D expenditures over the past 10 or 20 years provides no consistent base trend for projection, and the second because a clear set of national policy goals for science and technology has yet to be formulated. What is done herein is to raise the plausibility and reduce the variance of the expenditure projections by making clear the interrelationship between the gross levels of expenditure and the use of the scientific and engineering component of the labour force. One can either take the point of view that scientific and engineering manpower is a valuable resource to be exploited, and explore the implications of putting that resource to maximum use. Or one can begin from levels of expenditure one believes the economy "will be able to afford" or will deem desirable to spend, and explore the implications for future employment of scientists and engineers in Canada. The choice is immaterial as far as this document is concerned. Two previous Sections of this Report, projecting the likely supply of scientists and engineers, and the trends in costs per professional in R & D, have laid the basis for developing the projections, and for drawing from them some tentative conclusions for policy.

Procedure

As a matter of convenience, the projected scientific and engineering work force is used as the point of departure. Figures for 1965 in Canada give the proportion of the qualified scientists and engineers who were employed in R & D in that year as about 14 per cent. This proportion is compared with that in other countries to suggest a range of reasonable prospects for the future, that is, a range of plausible growth rates for the R & D work force. Combining those projections with an escalation factor for research costs then yields a range of projections for total national expenditure on R & D. Use of a projection of the Gross National Product to 1978 then allows translation of the results into the familiar terms of gross expenditure on R & D as a percentage of GNP. Needless to say, the reverse procedure could equally well have been applied, of taking a certain percentage of GNP in 1978 as a general goal or target, and deriving the consequences relative to the expected manpower supply.

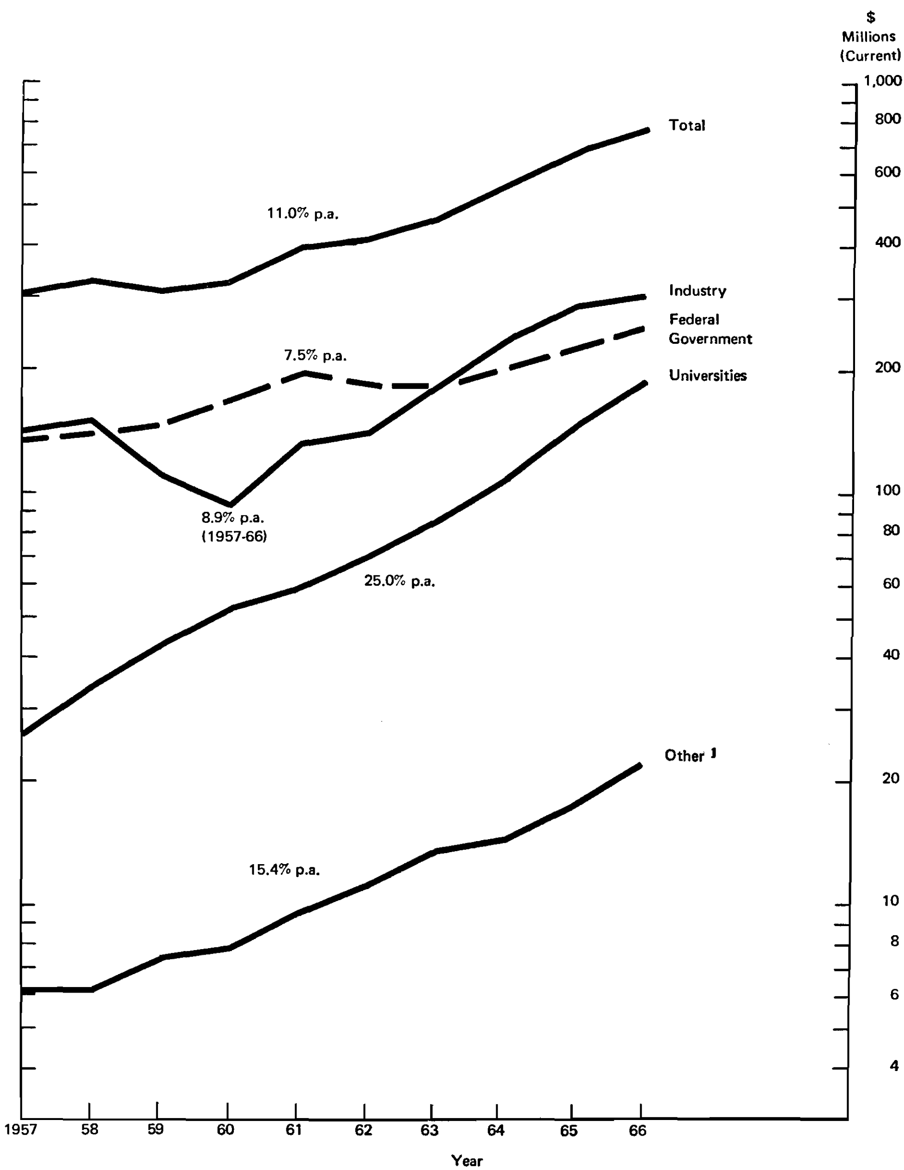
To go farther, into projections of the division of effort and funding among the sectors of the economy—government, university, and industry—it is necessary to make some additional assumptions. Projections of university enrolments, for example, provide a fairly firm basis for the growth of R & D expenditures in the academic sector, and this in turn restricts to a remarkable degree the range of possibilities open to the other two sectors within the total envelopes. Here again, no commitment to a policy assumption is meant to be implied. It would be equally valid to assume, say, a certain growth rate for industrial R & D and then to examine the implications for increasing or decreasing the rate of output from the Universities, or the amount of research done in-house in government laboratories, and so on. Our own experience has been that this procedure for examining the *interplay* between assumptions for the various sectors has been extremely instructive, and it is this feature we wish to emphasize rather than attaching any particularly great importance to any specific point of departure.

Past R & D Expenditures in Canada[1]

In Figure 14, the breakdown of the Canadian Gross Expenditures on R & D (G.E.R.D.) by sector of performance is shown for the period 1957 to 1966 in current dollars. The dip in industrial R & D activity reflects both the demise of the Arrow program and the economic recession in the latter 1950s. The overall average growth rate of G.E.R.D. over this period was 11.0 per cent per annum. Figure 15 shows the annual breakdown of the Canadian G.E.R.D. (1957 to 1966) by source of funds. In 1966, the Federal Government provided 51 per cent of all R & D funds in Canada.

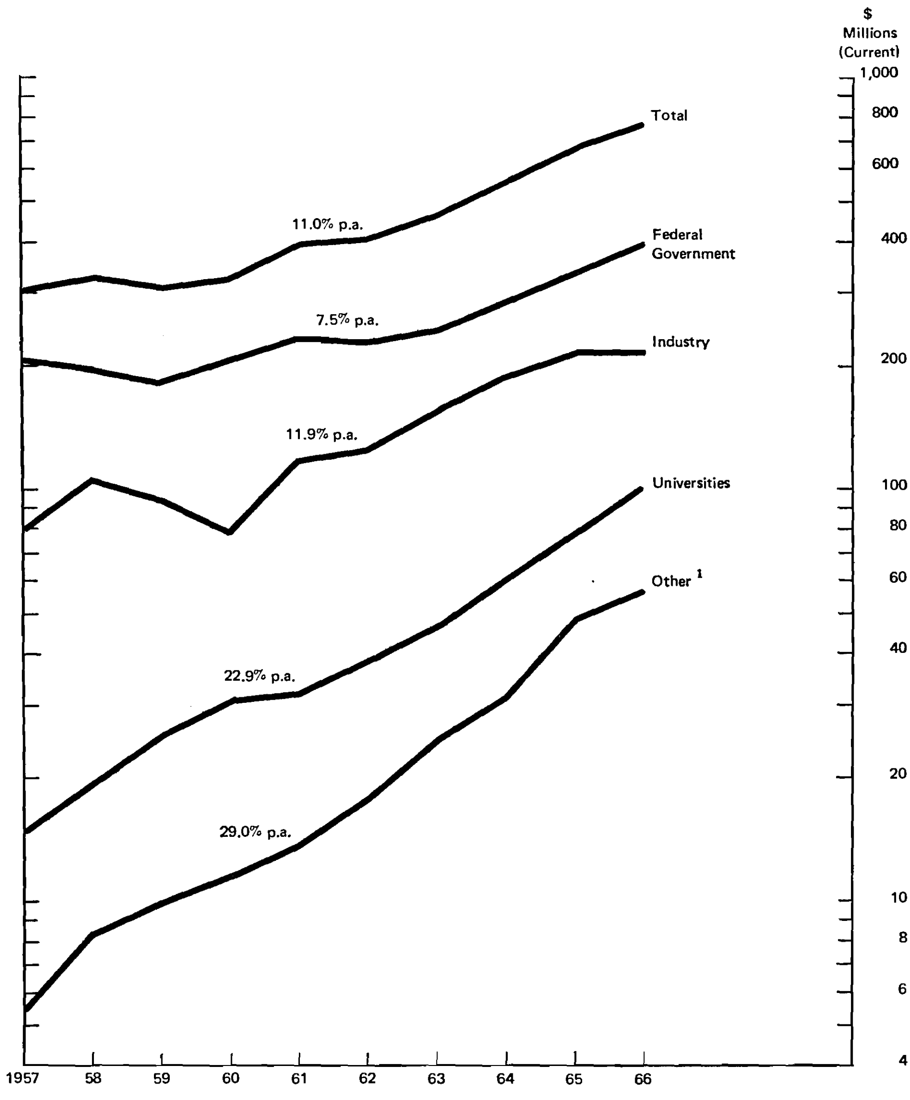
[1] The figures used herein for the past annual R & D expenditures (current and capital) for Canada were derived from DBS, DOI, NRC and other sources in an exercise undertaken by M. Eliesen of DOI, and G. T. McColm of the Science Secretariat. The figures for the R & D expenditures in universities were arrived at by estimations based on NRC publication No. 9196 and other material.

Figure 14.—Canadian Gross Expenditures (Current + Capital) on R & D 1957-1966 — by Performance



1 Private Non-Profit Plus Provincial Governments

Figure 15.—Canadian Gross Expenditures (Current + Capital) on R & D 1957-1966 — by Source of Funds



[1] Private Non-Profit Plus Provincial Government and Plus Foreign

Figures 16 and 17 show separately the current and capital components of the total expenditures. We hope the reader will not be confused by the two usages of the word "current": *current* as against *capital* expenditures, and *current* dollars as against *constant* dollars. The intended meaning should be clear from the context.

Other Background Material

Some further items of background material are essential to the development of argument herein.

(1) *The projection of the Canadian GNP to 1978*: In concert with the projection made by the Economic Council of Canada,[2] the real growth of the GNP is assumed to be 5.0 per cent per annum between 1966 and 1970, and 4.75 per cent per annum between 1970 and 1975. The latter growth rate is also assumed between 1975 and 1978 for the purposes of this study. An average implicit price increase (general inflation factor) of 2.0 per cent per annum is assumed between 1966 and 1978, in accordance with the goal recommended by the Economic Council. As a result of these assumptions, the GNP for Canada is projected to be 127.7 billion (current dollars) in 1978, as shown in Figure 18.

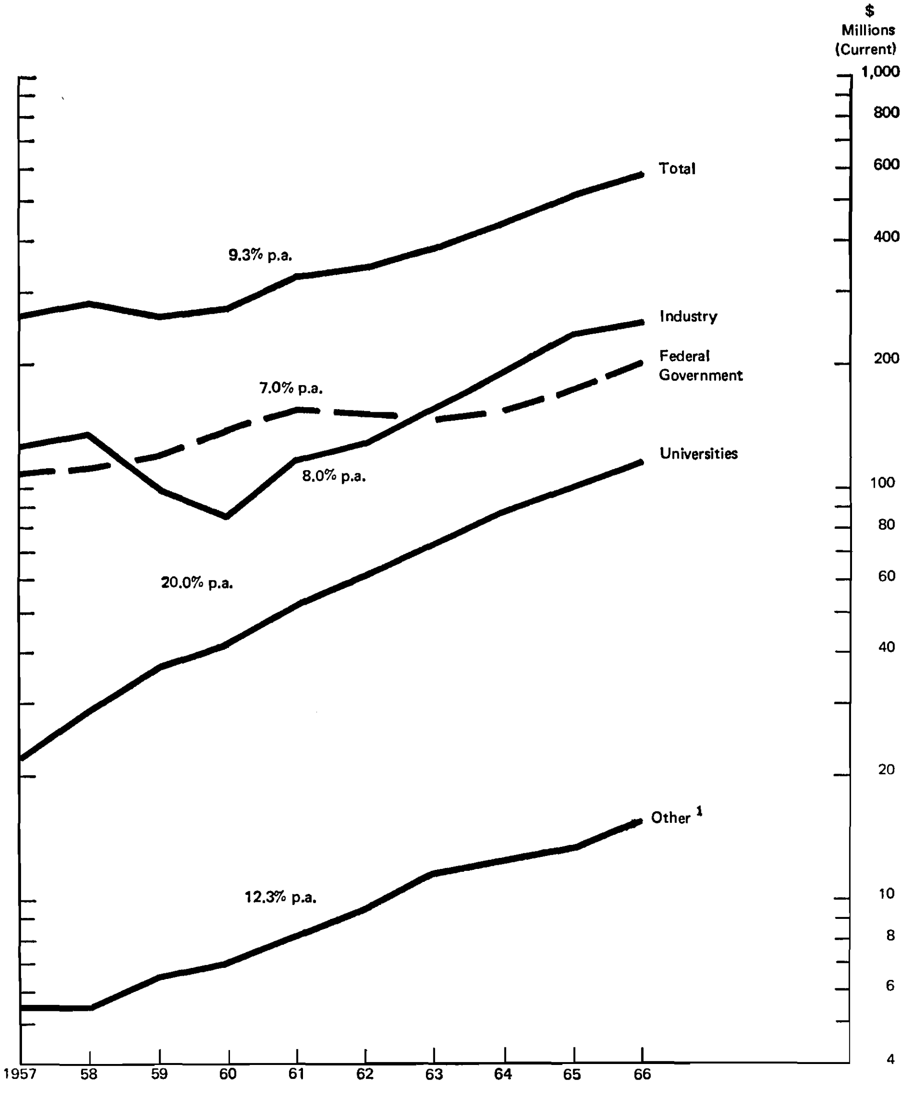
(2) *The number of scientists and engineers in the labour force in 1966 and the projected number for 1978*: These numbers are taken from Section 1 above and are, specifically, 113,000 for 1966 and 304,000 for 1978. For our purposes it is sufficiently accurate to assume a constant rate of annual growth over the intervening period.

(3) *The inflation-sophistication factor in R & D expenditures*: In the previous Section we concluded that the most reasonable value of annual escalation factor for R & D costs, as related to numbers of full-time professionals, would be 6 per cent per annum for projections over the next decade in Canada, under the conditions of general price inflation assumed for the GNP projection. This figure was based on past experience in the United States, Europe, and Canada.

(4) *The proportion of the scientific and engineering work force that is engaged in R & D*: As shown in Table 1, 14,910 scientists and engineers (full-time equivalent) were engaged in R & D in Canada in 1965. This represents 14.3 per cent of the scientists and engineers in the labour force at that time. The comparative figures for other countries are shown in Table 2. The other countries shown had about 20 per cent of their qualified scientists and engineers involved in R & D, with the exception of the United States, which had 33 per cent. The Canadian proportion in 1966 was assumed to be unchanged from 1965. The figure for total expenditure is reasonably consistent with that assumption.

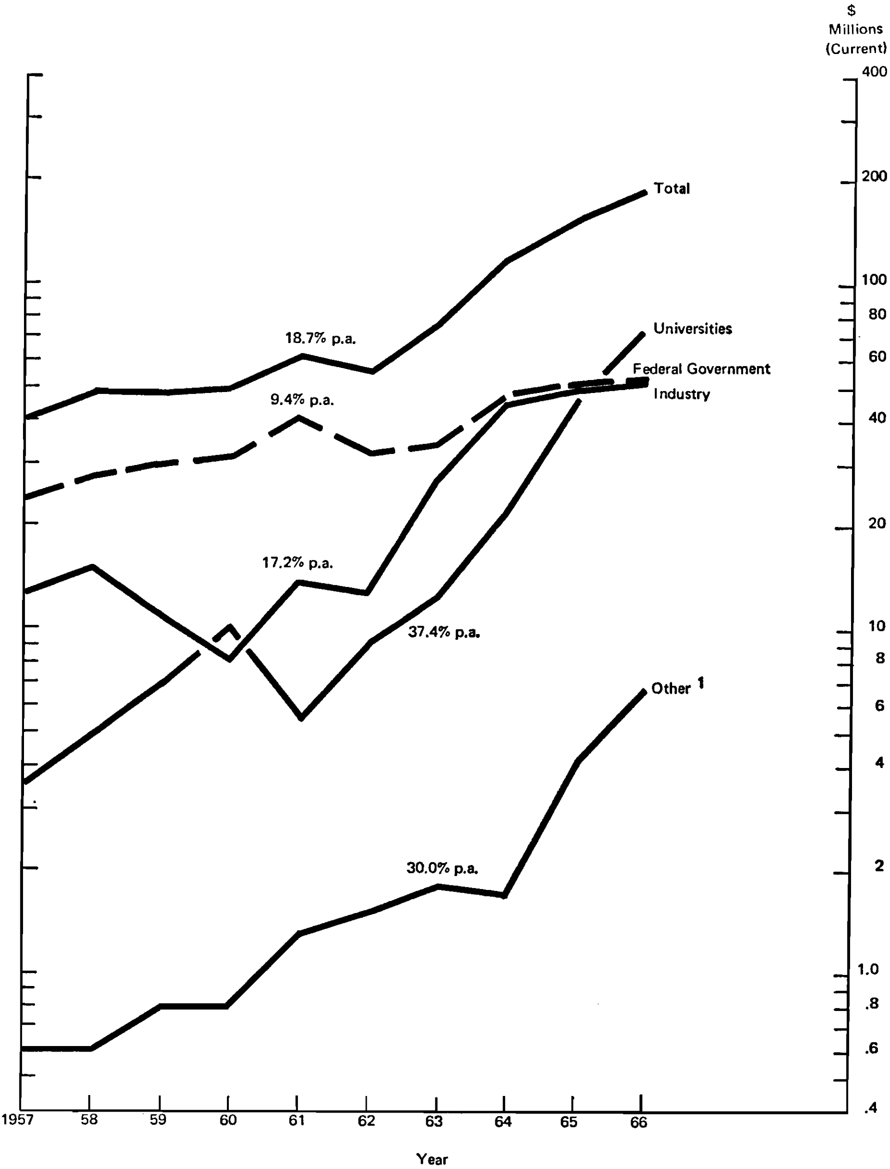
[2] Economic Council of Canada, *Fourth Annual Review*.

Figure 16.—Canadian Current Expenditures on R & D 1957-1966 — by Sector of Performance



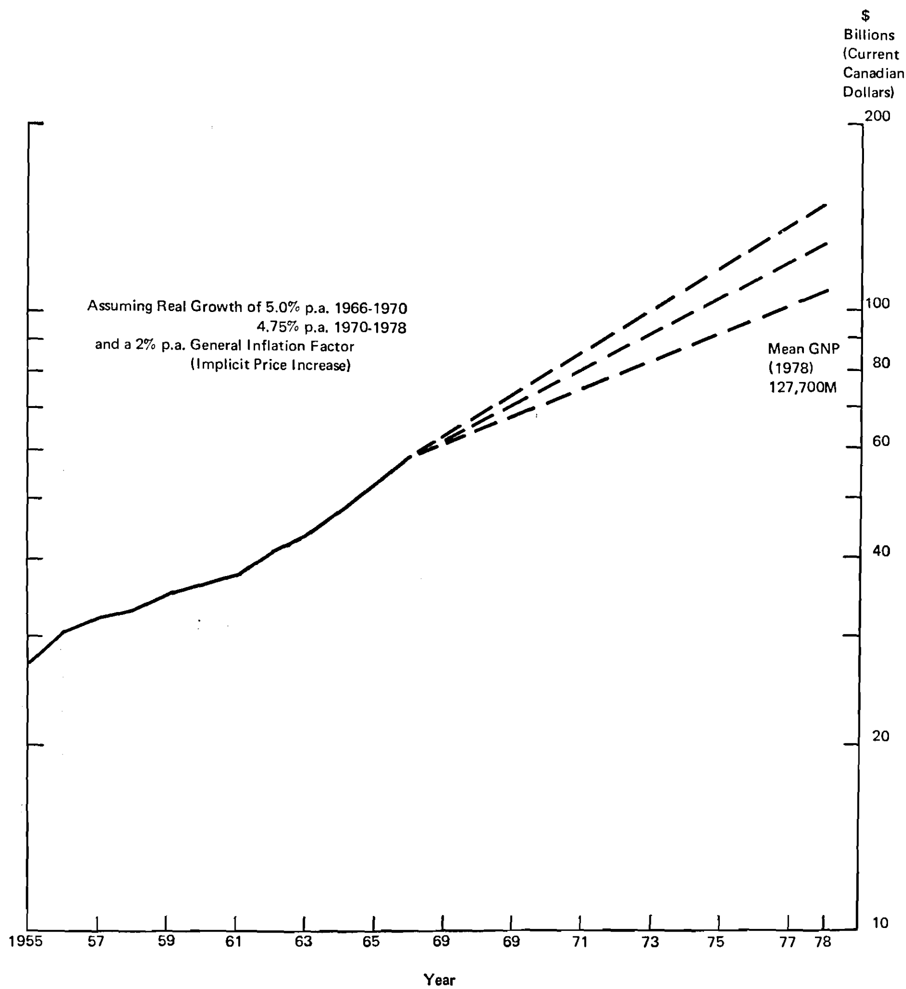
1 Private Non-Profit Plus Provincial Governments

Figure 17.—Canadian Capital Expenditures on R & D 1957-1966—by Sector of Performance



1 Private Non-Profit Plus Provincial Governments

Figure 18.—GNP of Canada in National Currency



Sources: Economic Council of Canada, Fourth Annual Review; U.N., Yearbook of National Account Statistics; U.N., Monthly Bulletin of Statistics. Assuming Real Growth of 5.0% p.a. 1966–1970, 4.75% p.a. 1970–1978, and a 2% p.a. General Inflation Factor (Implicit Price Increase).

Table 1.—Scientists and Engineers in R & D in Canada, 1965[1]

Sector	R & D Scientists and Engineers (FTE)
1. Federal Government	4,277[2]
2. Provincial research councils and foundations	270[3]
3. Provincial governments	232[4]
4. Industry	6,367[3]
5. Universities and colleges—	
Faculty members	1,400[5]
Postdoctoral fellows	320[5]
Higher degree candidates	1,680[6]
6. Non-profit organizations	364[7]
Total	14,910

[1] These figures were assembled by H. Stead of DBS for the Science Secretariat. They were derived in accordance with the procedures employed to obtain the same figures for 1963 for the OECD International Statistical Year report on R & D ("The Overall Level and Structure of R & D Efforts in OECD Member Countries", OECD, Paris, 1967).

[2] DBS 13–401; including DBS figures for the Institute of Avion Medicine. Medical science included.

[3] DBS 13-527; medical scientists included in industry, excluded in provincial research councils and foundations.

[4] DBS estimate based on 1963 figures.

[5] "Forecasting Committee of the National Research Council: Expenditures on Research in Science and Engineering at Canadian Universities", Economic Studies, ES 1, NRC No. 9196, September 1966. Medical science excluded.

[6] Derived from Reference [5] by DBS, using the same techniques as were used by DBS to derive the 1963 figure for OECD.

[7] DBS 13–526, "Expenditures on Scientific Activities by Non-profit Organizations, 1965".

Table 2.—Percentage of Scientists and Engineers Currently Engaged in R & D (full-time equivalent)

Country	Percentage
Canada (1965)	14.3[1]
U.S.A. (1965)	33.0[1]
U.K. (1965)	19.2[2,3]
France (1963)	19.1[2,4]
F.R. Germany (1961)	23.4[5]
Japan (1963)	16.6[2,6]
Sweden (1964)	21.6[7,2]

[1] Secretariat and DBS figures.

[2] "The Overall Level and Structure of R & D Efforts in OECD Member Countries", OECD, Paris, 1967.

[3] "Statistics of Science and Technology", HMSO, Dept. of Education and Science, Ministry of Technology, London, 1967; p. 39.

[4] "Resources of Scientific and Technical Personnel in the OECD Area", OEDC, 1963.

[5] "Reviews of National Science Policy—U.K. and Germany", OECD, 1967, p. 249.

[6] "Reviews of National Science Policy—Japan", OECD, 1966; p. 287.

[7] Estimate from reference 4.

Projection of the Gross Envelope

As a point of interest, the possibilities of simple trend projection are illustrated in Figure 19. A figure for gross expenditures in 1978 is assumed, as a percentage of projected GNP on that year, and is joined by a line of constant growth rate (a straight line on the logarithmic chart paper used) to the historical curve, the latest data point being 1966. The reader can exercise his judgment as to which line represents the most reasonable extrapolation from past history, and which would represent a clear break from present trends, etc.

To develop the expenditure projections from the basis of manpower use, the projected supply of scientists and engineers as developed in Section 1 was assumed, and four different levels of involvement of that work force in R & D were postulated for 1978—10 per cent, 14.3 per cent, 17 per cent and 30 per cent—all within the range of current practice in other countries, as shown in Table 2. The first level is lower than present (1965) Canadian involvement, the second assumes the maintenance of the present pattern, the third represents a modest increase, and the fourth represents an increase in the proportionate R & D involvement of the Canadian scientific and engineering work force toward present United States levels. Considering the present trends toward higher levels of education, the rising enrolments in graduate schools (where the emphasis is on research training), and the increasing pervasiveness and consciousness of technical change in our society, it would seem unlikely that the Canadian complement of R & D personnel among its scientific and engineering work force will be a smaller fraction ten years from now than it is today. But perhaps, when the financial implications are considered, a shift to the upper figure of 30 per cent will be seen to be equally unlikely. In any case, the lowest and highest postulated levels are intended to indicate reasonable outer limits of the possibilities, as seen from the present viewpoint.

Figure 20 shows the growth of the R & D scientific and engineering work force implied by the four assumptions. When an average inflation-sophistication factor in costs* per professional of 6 per cent per annum is assumed, as developed in Section 2, the results for the corresponding four projected levels of gross expenditure on research and development (G.E.R.D.) are shown in Figure 21. The implications for 1978 are summarized in Table 3. The figures for projected gross expenditures on R & D as a percentage of GNP range from 2.2 to 6.2 per cent.

For comparison, a similar exercise was done for the United States and is shown in Appendix A. The results are summarized in Table 4. Based on a projected continuing growth of the total United States scientific and engineering work force at about 5.9 per cent per annum, an involvement of a similar proportion in R & D to which is now involved (33%) will imply gross expenditures on R & D in 1978 amounting to between 5.4 per cent and 6.1 per cent of GNP.

* Note: Caution should be exercised in interpreting the meaning of "costs". The costs of obtaining scientific results are not necessarily rising, since the escalation could just as well derive from factors of rising R & D "productivity" per worker and/or rising productivity of investment in equipment as against investment in manpower. Analysis is not yet capable of settling the point.

Figure 19.—Gross Expenditures on R & D in Canada—Projected to 1978

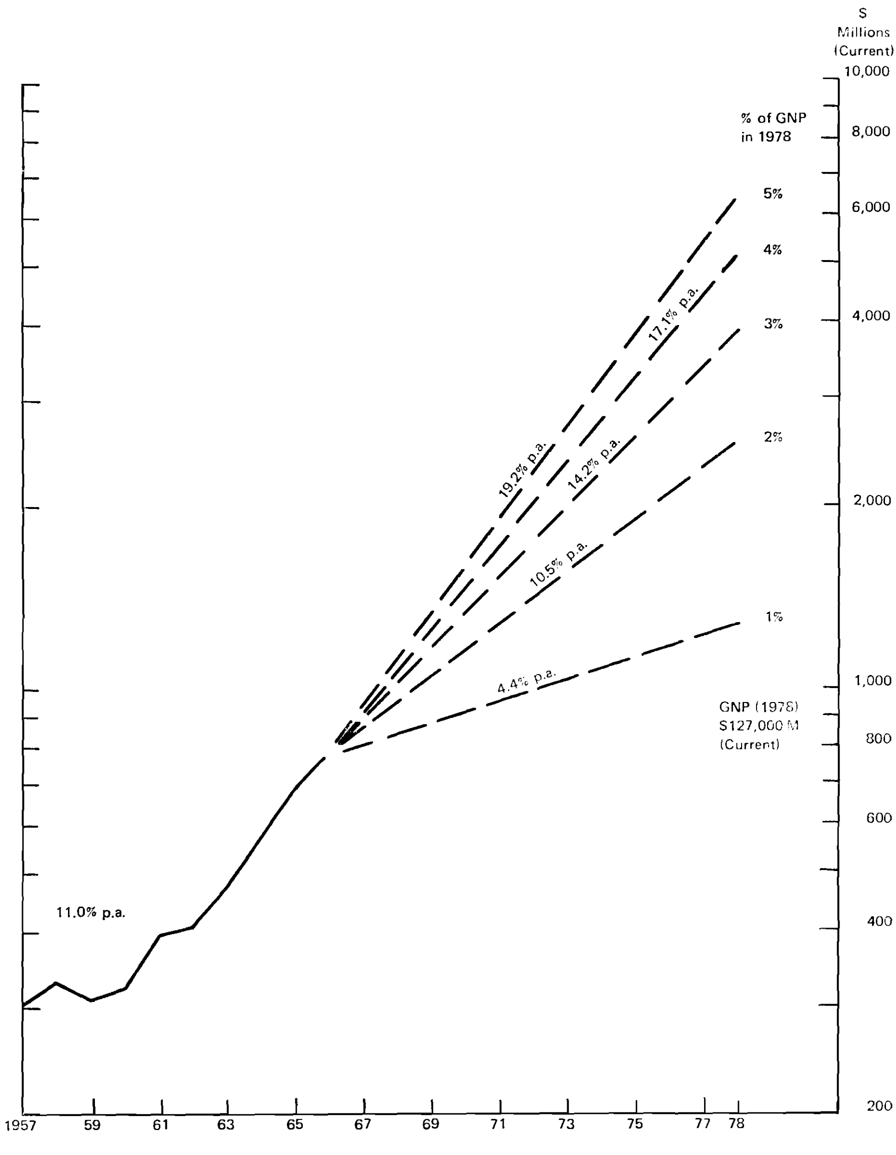


Figure 20.—Projections of Scientists and Engineers Engaged in R & D (FTE) in Canada

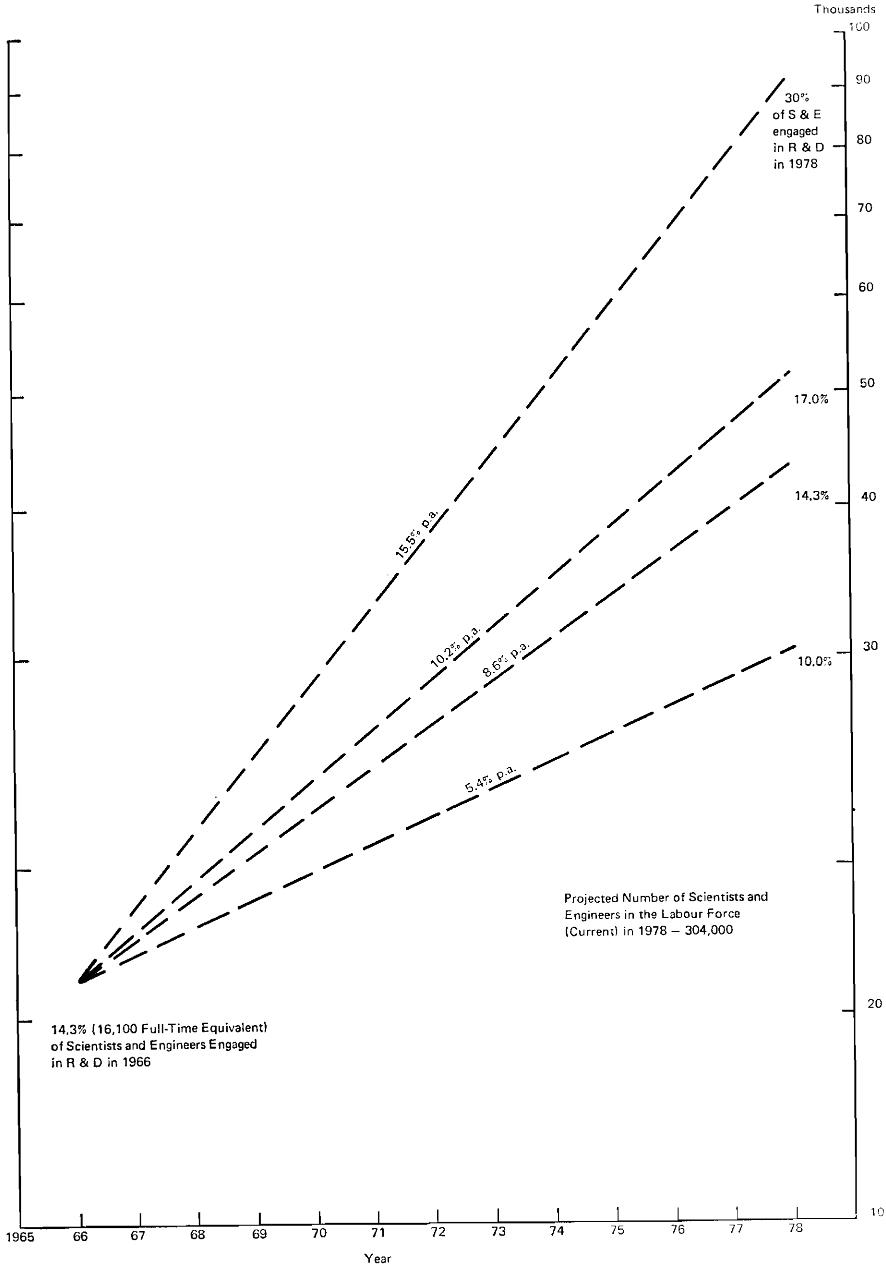


Figure 21.—Projections of G.E.R.D. to 1978

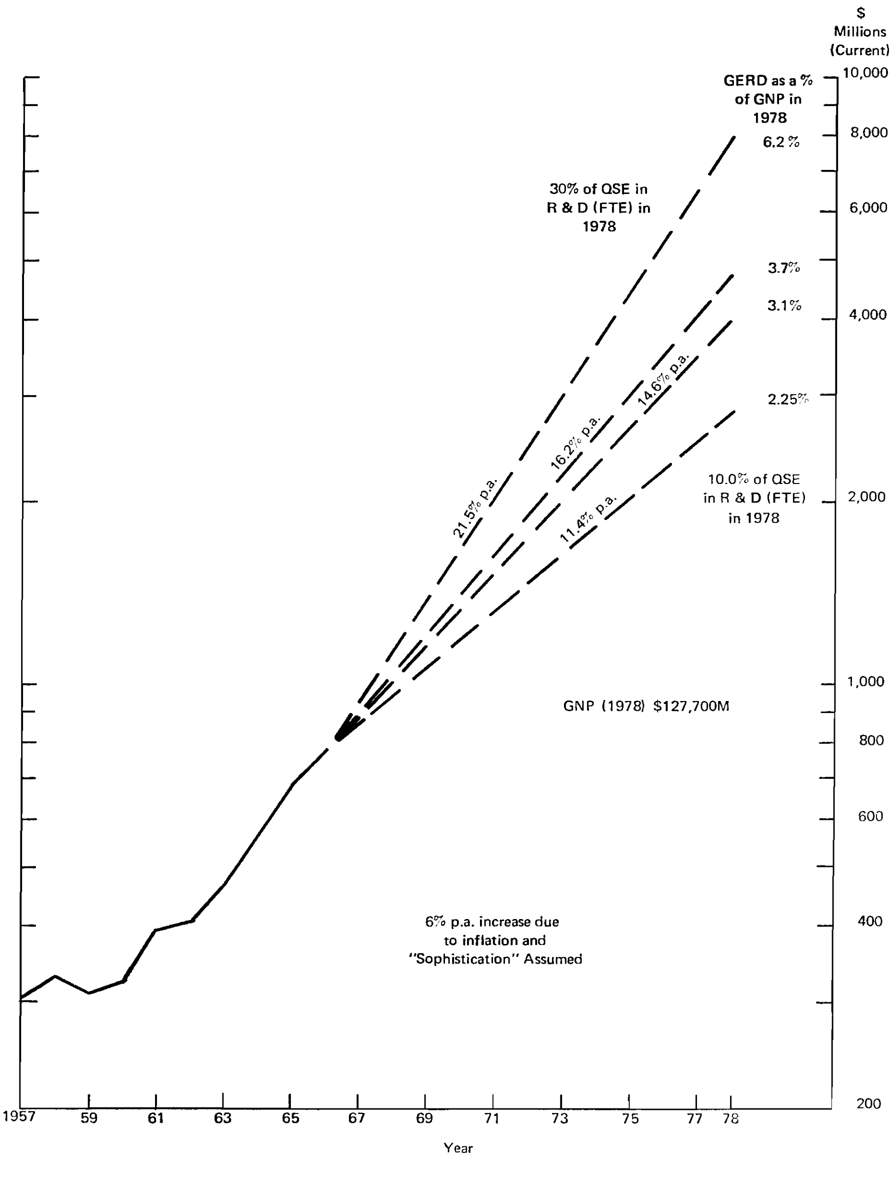


Table 3.—Implications of Manpower Involvement in R & D for levels of Gross Expenditure on R & D in 1978

CANADA

Item	Rate			
Percentage of Scientists and Engineers in R & D in 1978	10	14.3*	17	30
Growth rate of R & D manpower over period 1966-1978.. (per cent per annum)	5.4	8.6	10.2	15.5
Combined sophistication-inflation factor.......................... (per cent per annum)	6	6	6	6
Implied annual growth rate of total R & D expenditures (per cent per annum)	11.4	14.6	16.2	21.5
G.E.R.D. in 1978 ($ billions)..	2.8	4.0	4.7	8
Projected G.E.R.D. as a percentage of GNP in 1978......	2.2	3.1	3.7	6.2

* Present (1965) level.

To those who at the present time, for some reason or other, seem to regard a level of 3 per cent of GNP as approaching an all-time upper limit, these results will seem absurd. On the other hand, if the United States is regarded as progressing toward a "technological", "post-industrial", or "learning" society, it can be imagined that "R & D" will come more and more to describe simply *that which the scientist or engineer does*. It would then be seen as no cause for alarm that a substantial proportion of the population was scientifically and technically educated (and employed), and it would also be seen that to regard gross R & D expenditure as a national allocation of resources to something *separable and other* from the activities of the society in pursuit of its goals would be to misconstrue its significance as a social or economic indicator. Properly interpreted, we suggest, the gross national expenditure on research and development expressed as a percentage of GNP is simply an indicator of the degree to which the nation is using its scientific and technical resources

Table 4.—Implications of Manpower Involvement in R & D for levels of Gross Expenditures on R & D in 1978

UNITED STATES

Item	Rate		
Percentage of Scientists and Engineers in R & D in 1978..	20	33*	50
Projected G.E.R.D. as a percentage of GNP in 1978..........	3.3–3.7	5.4–6.1	8.1–9.1

* Present (1965) level.

(with more or less successful direction) toward the solution of its problems or the satisfying of its needs. These arguments are presented, not to argue for any particular set of curves, but only to caution the reader against excluding any particular set from his range of possibles without a careful examination of his preconceptions.

Sectoral Projections: Performance

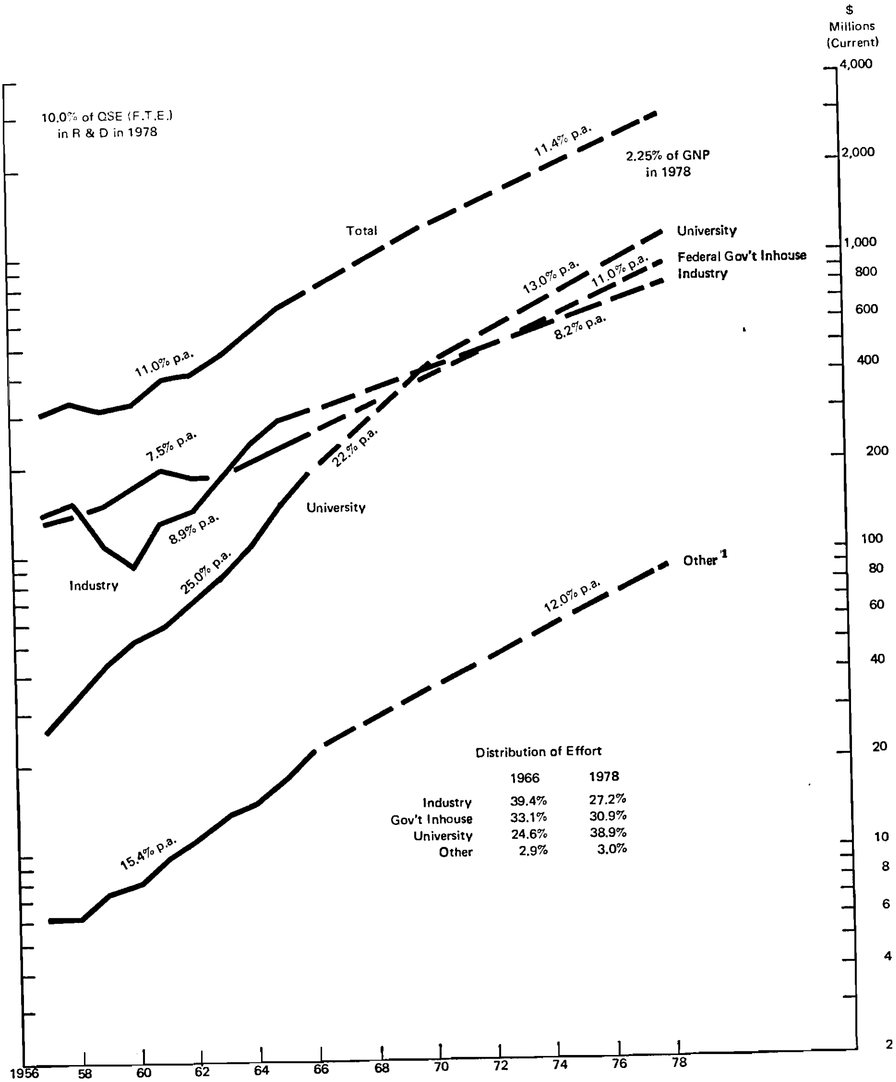
Four sectors of the economy in which R & D are performed are considered: government, university, industry, and "other", the last including private non-profit and provincial government research organizations. Within each of the four gross envelopes charted above, there are of course a very large number of possibilities. We can only sample here a few of the more reasonable ones to illustrate some of the implications inherent for policy.

The basis for projecting the growth of R & D in industry seemed particularly uncertain and consequently we chose to set down what seemed reasonable assumptions for the other three sectors, leaving industry to be determined as the dependent variable. As we have emphasized before, the procedure could just as validly be followed in another order, or the conditions could be entered on a computer and different assumptions tested at will. The reasoning used for the assumptions about R & D expenditures in the Federal Government (inhouse), university, and other sectors is as follows.

(1) *The "other" sector*:—The R & D expenditures in this sector grew between 1957 and 1966 at 15.4 per cent per annum. This fairly rapid growth was partly due to the enlargement of existing provincial government research establishments, and the addition of new establishments (such as certain provincial research councils) over this time period. A slower average growth of 12.0 per cent per annum (6.0% per annum growth in personnel) was assumed for the future, on the basis that the initial high costs of setting up organizations or expanding establishments to significant size have probably largely been met during the past few years. However, a large error in the assumed growth rate would have only a very small effect on the distribution of effort between the other sectors, since the expenditures in the "other" sector are relatively much smaller than those in the three main sectors. This 12.0 per cent per annum growth rate of R & D expenditures in the "other" sector is assumed in all of the four cases represented by Figures 22, 23, 24, and 25.

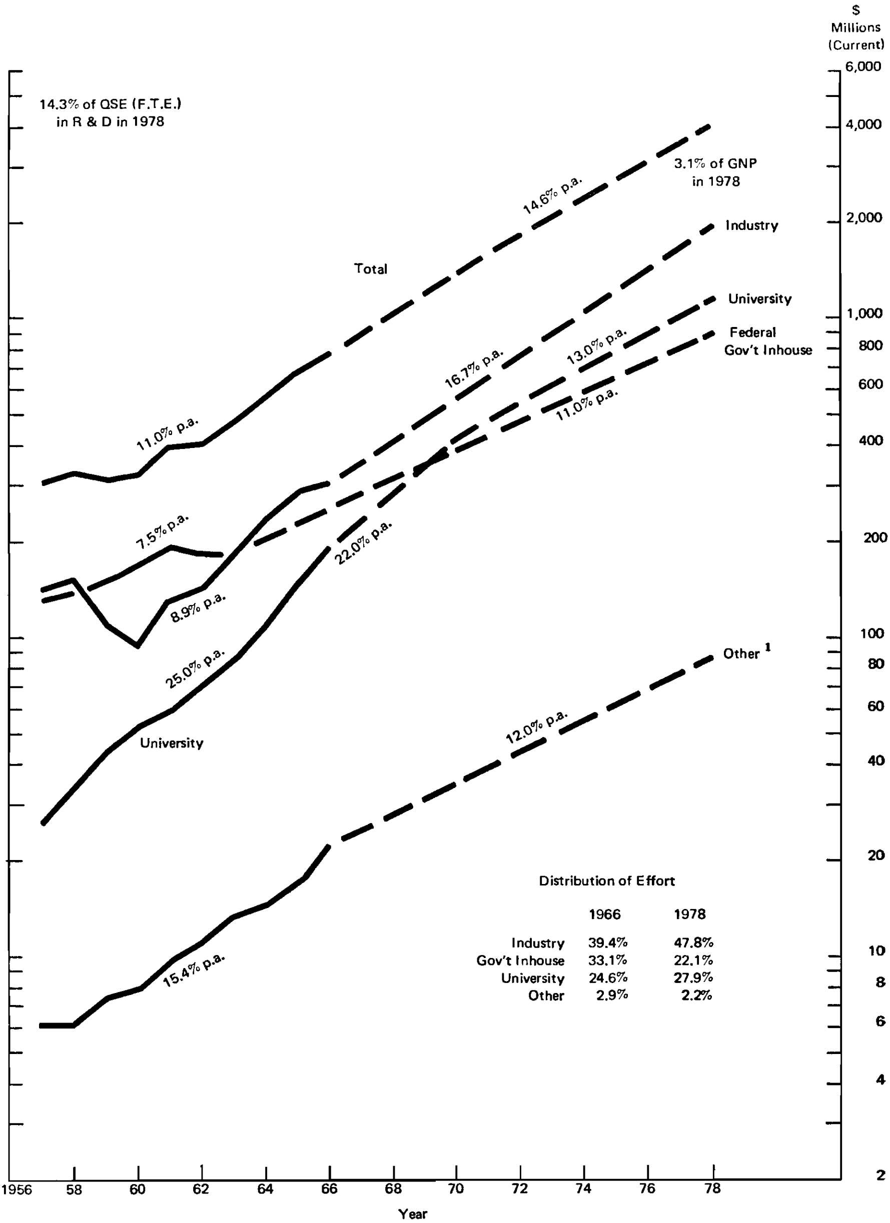
(2) *The Federal Government inhouse establishments*:—The overall average rate of growth of Federal Government inhouse R & D expenditures between 1957 and 1966 was 7.5 per cent per annum. This represents a very low rate of "real" growth (about 2.5% per annum) caused by the "austerity" program of the early sixties as well as other factors. In all of the four cases represented by Figures 9, 10, 11 and 12, a 5.0 per cent per annum growth in personnel is assumed between 1966 and

Figure 22.—Canadian Gross Expenditures on R & D Projected to 1978—by Performance



1 Private Non-Profit and Provincial Governments

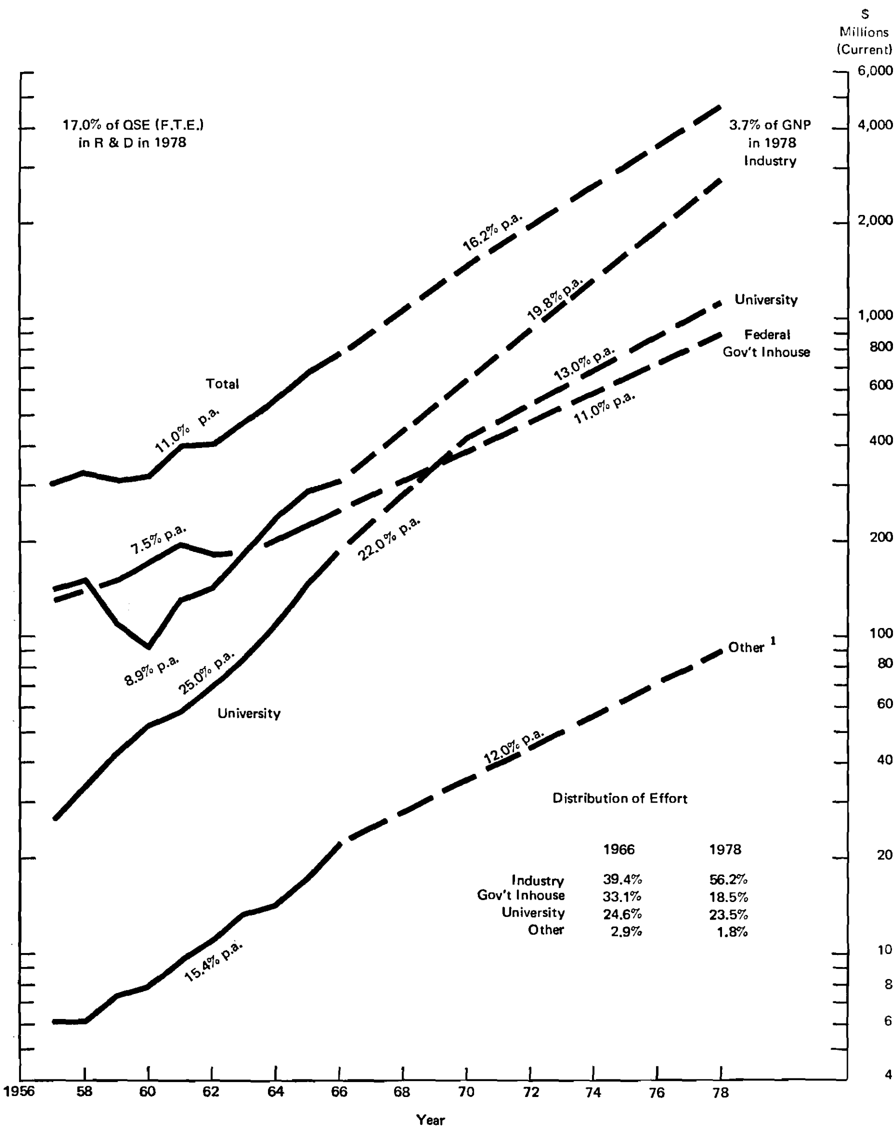
Figure 23.—Canadian Gross Expenditures on R & D Projected to 1978—by Performance



	1966	1978
Industry	39.4%	47.8%
Gov't Inhouse	33.1%	22.1%
University	24.6%	27.9%
Other	2.9%	2.2%

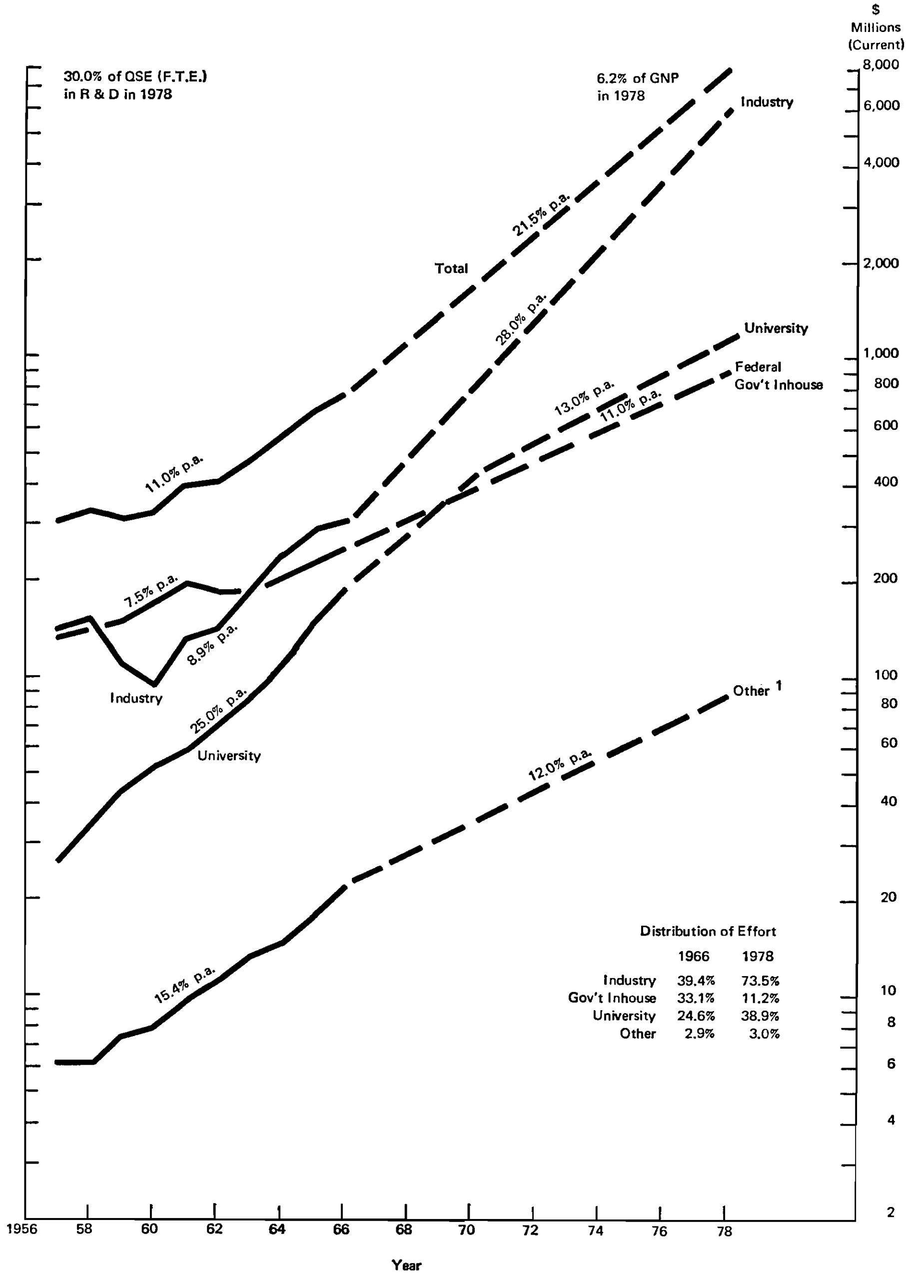
[1] Private Non-Profit and Provincial Governments

Figure 24.—Canadian Gross Expenditures on R & D Projected To 1978—by Performance



1 Private and Non-Profit and Provincial Governments.

Figure 25.—Canadian Gross Expenditures on R & D Projected to 1978—by Performance



[1] Private Non-Profit and Provincial Governments.

1978 (11.0% per annum apparent growth). This is a somewhat arbitrary choice of growth rate, but it allows the government inhouse R & D activities to expand at a "reasonable" rate as the responsibilities of the Federal Government increase to meet Canada's growing awareness of its needs. The reader, of course, is free to make alternative choices and examine their implications.

(3) *The university sector*:—Between 1957 and 1966, the R & D expenditures by the university sector grew at 25.0 per cent per annum. This was accompanied by a 20.0 per cent per annum growth in the graduate enrolment in science and engineering in Canadian universities over the same time period (Figure 26), indicating that the growth in the university sector's R & D expenditures (considering the R & D inflation-sophistication factor) was closely related to the rate of increase of graduate enrolment. It seems reasonable to assume that this relationship will continue in the future. The NRC Forecasting Committee[3] has projected a 16 to 17 per cent per annum increase in the graduate enrolment in science and engineering between 1966 and 1970, and a 7 per cent per annum increase between 1970 and 1976. We have assumed this latter rate of growth to continue to 1978. In accordance with these projections, which can reasonably be accepted as quite conservative[4] and thus almost as a lower limit, the rate of growth of R & D expenditures in the university sector is assumed minimally to grow at 22.0 per cent per annum (16.0% per annum personnel growth) between 1966 and 1970, and at 13.0 percent per annum (7.0% per annum personnel growth) between 1970 and 1978. These growth rates are assumed in all of the four cases represented by Figures 22, 23, 24, and 25.

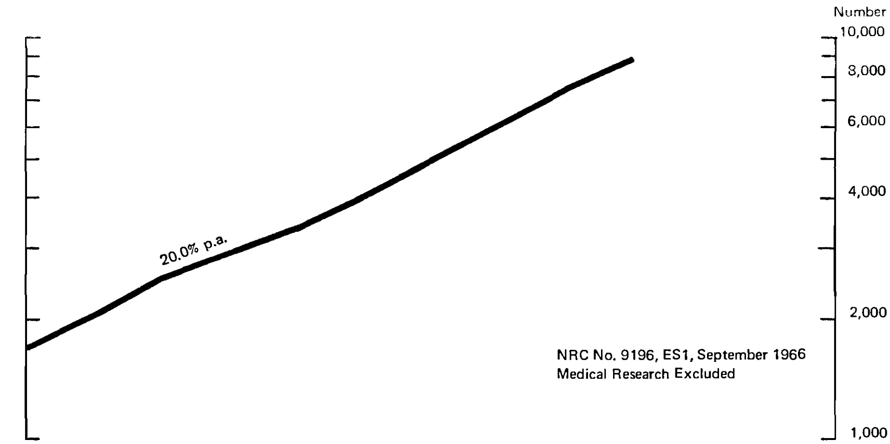
The consequences are exhibited in Figures 22, 23, 24, and 25. The first case, Figure 22, is that in which the involvement of engineers and scientists in R & D in 1978 is assumed to be 10 per cent of their total number. It can be seen that this allows a resultant growth in R & D expenditures in the industrial sector of 8.2 per cent per annum (2.2% per annum growth in personnel), compared to a past growth rate of 8.9 per cent per annum (average) between

[3] Forecasting Committee of the National Research Council, "Expenditures on Research in Science and Engineering at Canadian Universities", ES1, NRC No. 9196, September 1966. Graduate enrolment distinctly related to medical concerns is excluded.

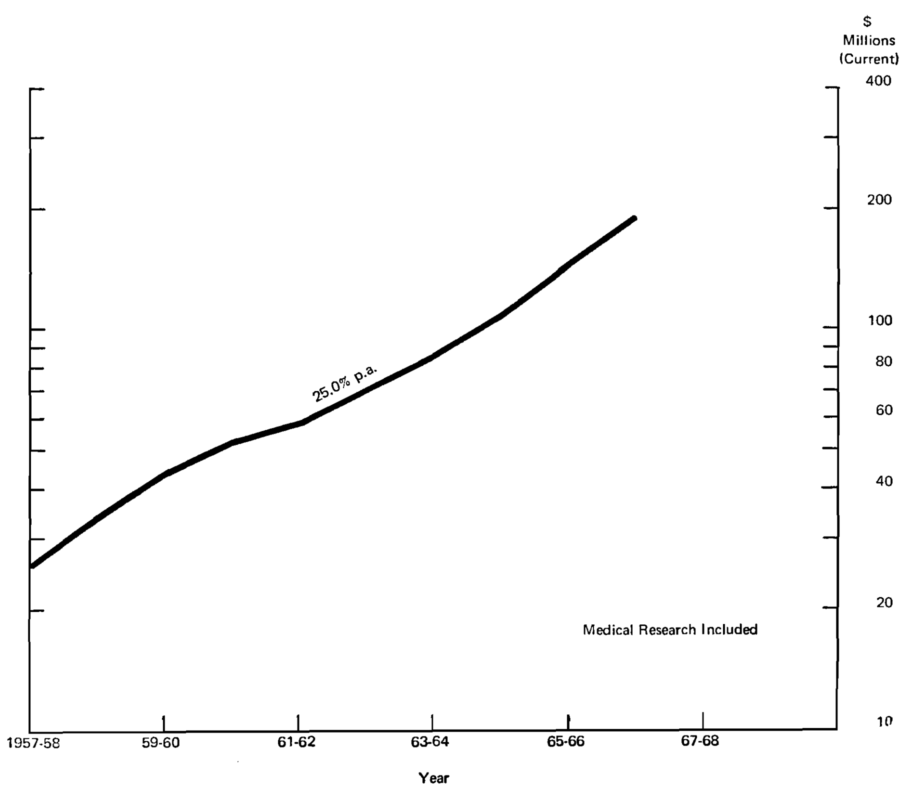
[4] In the Forecasting Committee's report (Reference 13), an alternative forecast was made of the rates of growth of graduate enrolment, namely 18% per annum between 1966 and 1970, and 12% per annum between 1970 and 1976. This forecast was higher because it was recognized that the first forecast was based on the individual university's assessments of the growth of their own graduate schools, and such projections would tend to be conservative. The first forecast implies that from 1970 on roughly the same proportion of each of the graduating classes of scientists and engineers would go on to graduate school. This seems an unlikely occurrence at this stage of university growth and development in Canada. Alternatively, it implies a slowing down in enrolment of foreign graduate students, who constitute 30% to 40% of present enrolments.

[5] This past experience, however, includes a serious set-back in industrial R & D expenditures occasioned by the cancellation of the Arrow project and economic difficulties at the end of the last decade.

Figure 26.—Candidates for Higher Degrees in Science and Engineering in Canadian Universities



R & D Expenditures in Canadian Universities



1957 and 1966.[5] This would result in a smaller proportion of the G.E.R.D. being performed in industry in 1978 (27.2%) than that performed in 1966 (39.4%). In view of the widespread present belief that a growing proportion of R & D in Canada should be performed in industry, this is not likely to be regarded as an acceptable outcome. One might rather see the growth rates of government and industry in this example interchanged. But even so, the growth rate in the university sector is such that the industrial proportion would still not quite maintain its present size, let alone approach the values at present prevalent in other developed countries,[6] which some people believe that it should. However, it is not productive to pursue this line of agrument too far because, in itself, it is hardly a sufficient basis for policy.

The second case (Figure 23) represents a constant involvement of 14.3 per cent (the 1965 proportion) of scientists and engineers in R & D. The resultant overall growth of R & D expenditures would be 14.6 per cent per annum, based on the projected growth rate of the total professional work force of 8.6 per cent per annum. The proportion of the R & D effort performed by industry in 1978 would then be 47.8 per cent, relative to 39.4 per cent in 1966.

In the third case (Figure 24, 17% of scientists and engineers engaged in R & D in 1978) the resultant rate of growth of gross R & D expenditures would be 16.2 per cent per annum between 1966 and 1978. Using the same assumptions as before for growth of government and academic research sectors, the proportion of the R & D effort performed in industry in 1978 then would be 56.2 per cent.

The fourth case (Fig. 25), where 30 per cent of the scientific and engineering work force in 1978 would be employed in R & D, would allow 75 per cent of R & D to be performed in industry, or alternatively, would imply sufficient growth as to offer scope for reconsideration of growth allocation in all sectors. This case represents a radical re-orientation of Canadian national purpose, which would result in gross expenditures on R & D rising annually by 21.5 per cent,* bringing about an increase in the numbers of scientists and engineers engaged in R & D of 14.9 per cent per annum.

It might be noted that all the above cases except the first one imply sustained growth rates of R & D manpower, and expenditure, that exceed those exhibited in the United States through the decade 1954-1964. This in itself should not be too surprising, in view of the unprecedently rapid expansion of the total Canadian labour force and the Canadian economy projected for the 1970s (see the Economic Council of Canada, *Fourth Annual Review*). Superimposed on the rapid population and labour force growth are the rising opportunities for education and, presumably, some component of an awakening or catching-up process which seeks to reduce the lead of the United States in

[6] In 1963–64, the major industrial countries performed between 60% and 70% of their R & D in the industrial sector—with the exceptions of the Netherlands (56%), France (51%) and Canada (41%). "The Overall Level and Structure of R & D Efforts in OECD Member Countries", OECD, Paris, 1967.

* Actually higher, since such a growth has obviously not yet started, as of 1968.

science and technology. Nevertheless, the comparison does serve to emphasize that the high rates of growth which are predicted for Canadian R & D may present some problems for national policy.

One moral that might be drawn is that, when a total system is in such a state of rapid growth, it must be expected that interrelated elements will grow in an organically related way, If, as an extreme example, policy were such as to try to hold down the level of expenditures on R & D to the 1966 level of about 1.3 per cent of GNP, if, furthermore, the scientific and engineering work force continued to grow as projected, and if the universities continued to expand to meet the demand for higher education on the (conservative) projection used above, then in 1978 besides a probable widespread unemployment and underemployment of engineers and scientists we would find that two-thirds of the R & D effort in Canada at that time was being done in the universities.

Sectoral Projections: Source of Funds

For developing projections of where the funds in support of R & D might come from, there is little basis other than simple trend projection, until some policy decisions are made regarding the topics of national priority, and how the (presumably) increasing Canadian efforts in R & D might be organized. Consequently, we present only one projection, a "median" choice, with somewhat arbitrary though reasonable assumptions, for illustrative purposes only.

The example assumes the level of involvement of scientists and engineers in R & D to 1978 to be constant at the 1965 level (14.3%). Figure 27 shows, to begin with, the past pattern of expenditure by source and then projects the curves to 1978 with the following assumptions.

The "other" sector[7] grew rapidly as a source of funds between 1957 and 1966 (29% per annum). Most of this (62% in 1966) was from foreign sources, chiefly from the United States. This is likely to be a weaker source in the future, judging from present economic and political concerns in the United States. We have therefore projected a much more modest growth at 11 per cent per annum to 1978.

The funds for R & D from the university sector grew at 22.9 per cent per annum between 1957 and 1966. We assumed a lower rate of growth, 16 per cent per annum, from 1966 to 1978 for two reasons. Continuing needs for expansion of undergraduate facilities will strain provincial government budgets, and the enrolment projection used assumes a pronounced easing of the expansion rate of graduate schools from 1970 on.

The funds for R & D from the industrial sector grew at 11.9% per annum between 1957 and 1966. As long as the various incentive programs continue, and as long as the continued growth of secondary industrial manufacturing is

[7] Private non-profit, provincial government, and foreign.

strongly encouraged, one might reasonably project that the R & D funds emanating from the industrial sector would grow at a rate of 12% per annum between 1966 and 1978.

Between 1957 and 1966, the R & D funds emanating from the Federal Government increased (overall average) at 7.5 per cent per annum. As the remaining sector under the total envelope (the case chosen for illustration reaches a level of 3.1 per cent of GNP in 1978) after the above assumptions have been made, the Federal Government funding would have to grow at 16.2 per cent per annum from 1966 to 1978.

The R & D funds provided by the Federal Government for work in all sectors amounted to $396.6 million in 1966. The above projected growth rate would bring the Federal funding to $1,300 million (current dollars) in 1974, $1,760 million in 1976, and $2,370 million in 1978, an increase of a factor 4.4 over a decade. In fiscal year 1966 (calendar 1966–67) the Federal expenditures on R & D represented 4.5 per cent of the Federal budget ($8,798 million), and the budget, in turn, was equivalent to 15.2 per cent of the GNP in 1966—about the same, on the average, as for the previous five years.[8] In the United States, the corresponding figures for 1966 were 15 and 14.4 per cent, respectively.[9] If the functions and responsibilities of the Canadian Federal Government are assumed to be the same in 1978 as today, then the Federal Government budget might be expected to be the same percentage of the GNP as it is today. This would amount to $19,400 million (current dollars). The Federal R & D expenditures would then amount to 12.2 per cent of the Federal budget in 1978—a considerable increase from the present proportion, but still not exceeding the proportion of resources allocated to R & D in the United States federal budget for 1966.

The shift of resources for R & D in the Federal Government budget from 4.5 per cent in 1966 to 12.2 per cent in 1978 would be a considerable shift, but not an unprecedented shift, by any means, compared to what has happened in other countries over the past few years. The experience in the United States, France, Federal Republic of Germany, and Canada is shown in Table 5 and Figure 28. While the federal governments of the three other countries were significantly shifting their resources to the funding of R & D, the Canadian government was not. Thus, while the rate of rise of the relative importance of R & D in the Canadian Federal budget, implied by the above figures, would show a steepness intermediate between the curves shown for France and the United States in Figure 28, part of the rapidity of the shift could easily be attributed to a "rebound" effect from the period of arrest that preceded it. In any case, the comparisons demonstrate that it is quite possible for countries to shift their federal government financial resources to the degree implied by the sample projection in Figure 27 if they choose to do so.

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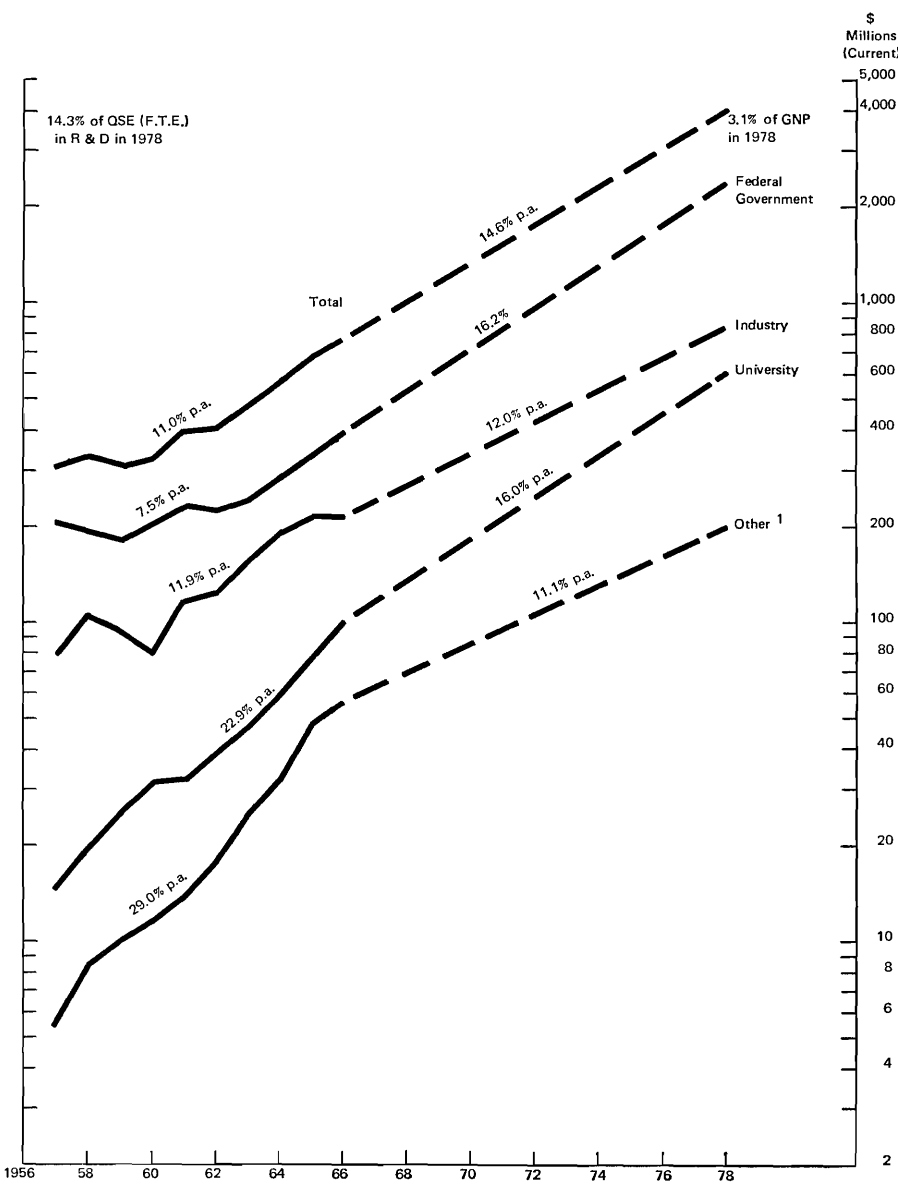
[8] *Estimates.* The estimates of the Canadian Federal Government, published annually by the Queen's Printer, Ottawa.

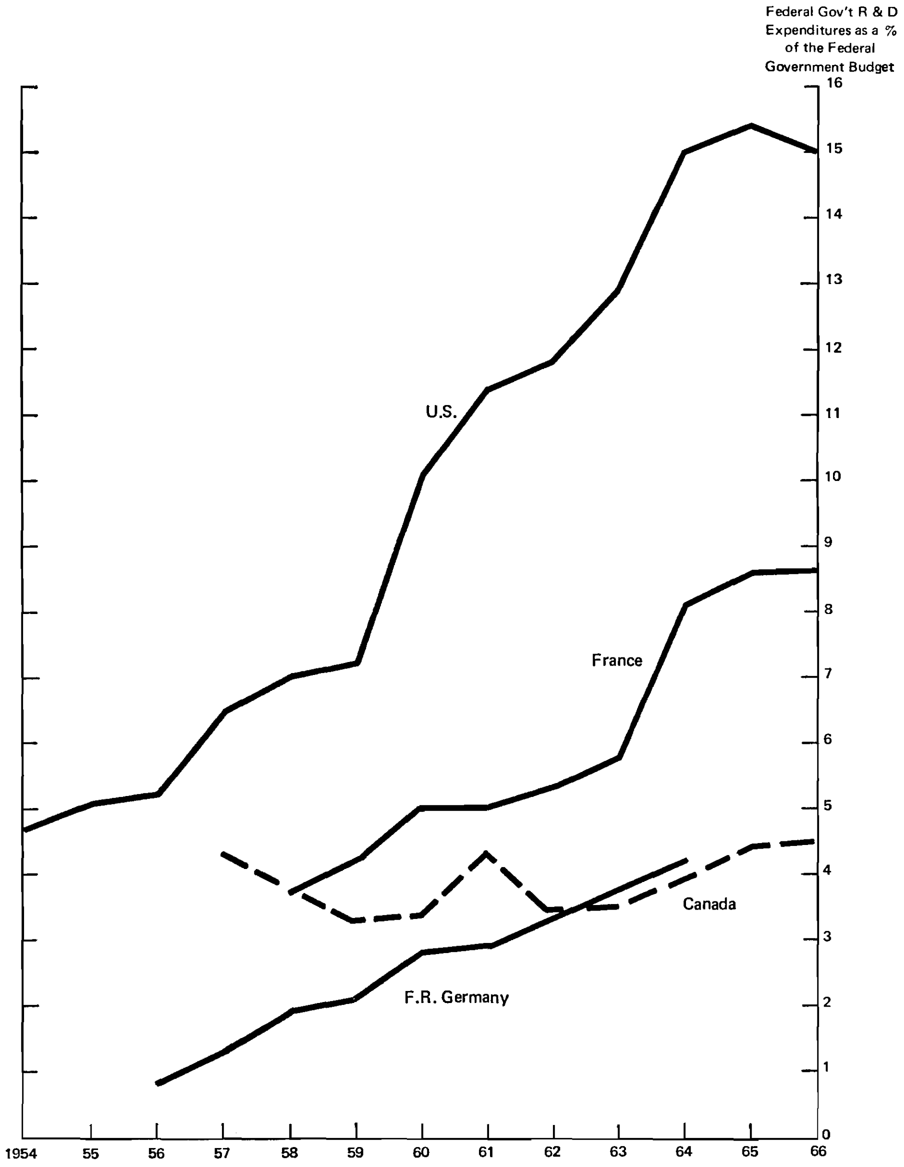
[9] NSF 67–19.

Figure 27.—Canadian Gross Expenditures on R & D Projected to 1978—by Source



[1] Private Non-Profit, Provincial Government and Foreign

Figure 28.—Percentage of Federal Government Budgets Allocated to R & D



In absolute terms, as a matter of history, federal government R & D expenditures, in current funds, grew at rates of 14.6 per cent per annum (average) in the United States over the period from 1954 to 1966, 21.6 per cent per annum in France from 1958 to 1966, 35 per cent for F. R. Germany from 1956 to 1965, and only 7.5 per cent per annum for Canada between 1957 and 1966 (see Table 6 and Figure 27). Thus, while the trends projected might be regarded as a break with Canadian tradition, they do not necessarily represent growth rates over the coming decade that would be unreasonable or unmanageable. As to whether they would be reasonable over a longer term, that is another question. To answer it, some new factors would have to be brought into consideration, and the implications of these various growth processes in our society (and the meaning of our economic indicators) would have to be re-examined in a very fundamental way.

Conclusions

We believe that the exercise presented has demonstrated the utility for science policy-making purposes of attempting to project the future macroscopic consequences of various reasonable policy decisions or assumptions. It is only a beginning at what could be accomplished with more refined (computer) methods, less brutal assumptions, and better data. In particular, the manpower projection developed in Section 1 plays a very important role and it is only fair to draw attention to the nature of the assumptions made therein, and the inadequacy of the existing data. The scientific and engineering work force could grow more slowly than projected, but also there are factors, such as immigration, that could make the projection over-conservative.

Table 5.—The Relationship Between the Canadian Federal Government Budget and the GNP

Item	1961	1962	1963	1964	1965	1966
Federal Government[1] budget ($ millions)	6520.9	6570.3	6872.4	7218.3	7734.8	8797.7
GNP of Canada[2,3] ($ millions)	37,435	40,520	43,142	47,703	52,109	57,800
Federal Government budget as a percent of GNP	17.4%	16.2%	15.9%	15.1%	14.8%	15.2%
Average (1961-1965)						15.8%

[1] *House of Commons Debates*, Vol. III, No. 51 (March 29, 1966), and Vol. 112, No. 18 (June 1, 1967); 1966 figure supplied by DBS.

[2] U.N., *Monthly Bulletin of Statistics*.

[3] U.N., *Yearbook of National Accounts Statistics*.

Table 6.—Federal Governments' Budgets and R & D Expenditures in all Sectors—U.S., France, F.R. Germany and Canada

	1954	1955	1956	1957	1958	1959	1960
U.S.A.[1] (1966=1965-1966)							
1. Federal government R & D expenditures[2] ($ U.S. millions)	3,148	3,308	3,446	4,462	4,990	5,803	7,738
2. Total federal government budget ($ U.S. millions)	67,537	64,389	66,224	68,966	71,369	80,342	76,539
3. 1. as a percentage of 2	4.7	5.1	5.2	6.5	7.0	7.2	10.1
France							
1. Federal government R & D expenditures (millions of francs)					1,704[3]	2,138[3]	2,712[3]
2. Total federal government budget (billions of francs)					46.70[5]	51.19[5]	54.53[5]
3. 1. as a percentage of 2					3.7	4.2	5.0

Table 6.—Federal Governments' Budgets and R & D Expenditures in all Sectors—U.S., France, F.R. Germany and Canada *(continued)*

	1961	1962	1963	1964	1965	1966
U.S.A.[1] (1966 = 1965-1966)						
1. Federal government R & D expenditures[2] ($ U.S. millions)	9,278	10,373	11,988	14,694	14,875	16,002
2. Total federal government budget ($ U.S. millions)	81,515	87,787	92,642	97,684	96,507	106,978
3. 1. as a percentage of 2	11.4	11.8	12.9	15.0	15.4	15.0
France						
1. Federal government R & D expenditures (millions of francs)	3,024[3]	3,666[3]	4,504[3]	6,680[3]	7,530[4]	8,164[4]
2. Total federal government budget (billions of francs)	60.88[5]	69.88[5]	77.22[5]	82.73[5]	87.86[5]	95.19[6]
3. 1. as a percentage of 2	5.0	5.3	5.8	8.1	8.6	8.6

[1] NSF 67–19 (Vol. XVI, p. 2).

[2] R & D and R & D plant expenditures. Amounts include pay and allowance of military R & D personnel for both obligations and expenditure.

[3] DGRST: Les Moyens Consacrés par l'état à la Recherche et au Développement en 1964, p. 32.

[4] Les Progrès Scientifiques, No. 114, December 1967: DGRST, p. 72.

[5] National Account Statistics, 1956–1965, OECD; p. 139.

[6] Document of International Monetary Fund, SM/66/136, Supplement 1, January 10, 1967. France—1966 Article VIII consultation, p. 28: Table 14. Central Government Budget (excluding loans).

Table 6.—Federal Governments' Budgets and R & D Expenditures in all Sectors—U.S., France, F.R. Germany and Canada (*continued*)

	1954	1955	1956	1957	1958	1959	1960
F. R. Germany							
1. Federal government R & D expenditures (millions of DM)			170.5[7]	332.7[7]	527.1[7]	614.2[7]	898.7[7,8]
2. Total federal government budget[11] (billions of DM)			22.46	24.95	27.10	29.79	32.12
3. 1. as a percentage of 2.			0.8	1.3	1.9	2.1	2.8
Canada (1965 = 1965-1966)							
1. Federal government R & D expenditures[12] ($ Can. millions)				206.0	196.0	180.5	202.0
2. Total federal government budget ($ Can. millions)				4,775[13]	5,231[13]	5,539[13]	5,885[13]
3. 1. as a percentage of 2.				4.3	3.8	3.3	3.4

Table 6.—Federal Governments' Budgets and R & D Expenditures in all Sectors—U.S., France, F.R. Germany and Canada (*concluded*)

	1961	1962	1963	1964	1965	1966
F. R. Germany						
1. Federal government R & D expenditures (millions of DM)	1.074.5[7]	1,401.8[9]		2,040.6[10]		
2. Total federal government budget[11] (billions of DM)	36.41	42.05	45.77	48.40		
3. 1. as a percentage of 2.	2.9	3.3		4.2		
Canada (1965 = 1965-1966)						
1. Federal government R & D expenditures[12] ($ Can. millions)	230.7	225.8	240.3	281.8	336.5	396.9
2. Total federal government budget ($ Can. millions)	6,254[13]	6,638[13]	6,739[13]	7,160[13]	7,537[13]	8,797.7[14]
3. 1. as a percentage of 2.	4.3	3.4	3.5	3.9	4.4	4.5

[7] Country Report on the Organization of Scientific Research—Germany, OECD; p. 66. Including social sciences.

[8] Estimated 12-month figure.

[9] Review of National Science Policy—U.K. and Germany, OECD: p. 203.

[10] Bundesbericht Forschung II; Der Bundesminister Fur Wissenschaftliche Forschung; pp. 212-213. Including social sciences.

[11] National Account Statistics, 1956–1965, OECD; p. 139. 1956–1959 exclude figures for West Berlin and the Saar.

[12] Science Secretariat figures (see Figure 17).

[13] National Account Statistics, 1956–1965, OECD; p. 39.

[14] From DBS.

Appendix A

PROJECTIONS OF UNITED STATES SCIENCE AND ENGINEERING STATISTICS TO 1978

The following exercise is tentative and indicative, partly because the present problems confronting the United States render any projections of expenditures and manpower usage extremely risky. Nonetheless, a reasonable attempt will be made to project to 1978, on a "surprise-free" basis, the size of the "current" stock of scientists and engineers in the United States labour force[1], the numbers of these who might reasonably be involved in R & D activities (full-time equivalent), and the corresponding gross expenditures on R & D (G.E.R.D.) for the United States in constant 1965 dollars.

The "Current" Stock of Scientists and Engineers in the Labour Force in 1978

In 1963, the current stock of scientists and engineers in the United States labour force was 1,360,000[2]. Table 1A shows the method of calculating the current stock of scientists and engineers in the United States labour force in 1965, the base period for this exercise, as well as projecting this current stock to 1978. Attrition (due to death or retirement), first degree graduations (Figure 29), immigration and net transfers (apart from attrition) out of the current stock of scientists and engineers in the labour force are all taken into account. The current stock of scientists and engineers in the United States labour force in 1978 is projected to be 3,190,000 (rounded; Figure 30).

The Number of Scientists and Engineers Engaged in R & D

In 1965, 503,600 (full-time equivalent) scientists and engineers were engaged in R & D activities in the United States[3]. This represents about 33 per cent of the scientists and engineers in the labour force at that time. Three separate assumptions were made concerning the percentage of the scientists and engineers involved (FTE) in R & D activities in 1978; namely, that only 20 per cent

[1] "Current" as opposed to "potential". The "potential" stock of scientists and engineers would include all those in the labour force who had been trained in science and engineering (as well as those not in the labour force but younger than retirement age, such as housewives), while the "current" stock includes those in the labour force who are employed in jobs requiring to some degree a scientific or engineering training. Graduate students are included in both definitions in view of their R & D activities and their important teaching functions. A tighter definition of "current" is sometimes used in which only those who are directly involved in science and engineering activities are counted—but the purpose here is to include a wider spectrum of the technostructure.

[2] NSF 64-28. Includes natural sciences, mathematics, engineering, forestry science, agricultural science, veterinary science and those medical scientists in R & D and production functions. Excludes social scientists. Includes people with a training at least equivalent to a four year university programme. Excludes people trained as scientists or engineers who are currentlv employed in jobs not requiring such training to any extent.

[3] NSF 67-7; p. 9.

Table 1A.—The "Current" Stock of Scientists and Engineers in the United States Labour Force to 1978

Year	Attrition (1.5 % per annum)[a]	Bachelor and First Professional Degree Granted[b]	Immigration into U.S.[c]	Net transfer out of science and engineering labour force[d]	Total net Addition to Labour Force	"Current" Science and engineering Labour Force (rounded)
1963......	—	—	—	—	—	1,360,000
1964......	−20,400	104,005	5,401	−10,400	78,606	1,439,000
1965......	−21,570	110,156	5,004	−11,016	82,574	1,521,000
1966......	−22,800	110,200	6,773	−11,020	83,153	1,604,000
1967......	−24,050	118,550	6,000	−11,855	88,645	1,693,000
1968......	−25,380	141,400	6,000	−14,140	107,880	1,801,000
1969......	−27,000	156,330	6,000	−15,633	119,697	1,921,000
1970......	−28,800	156,800	6,000	−15,680	118,320	2,039,000
1971......	−30,500	160,970	6,500	−16,097	120,873	2,160,000
1972......	−32,350	168,730	6,500	−16,873	126,007	2,286,000
1973......	−34,300	178,380	6,500	−17,838	132,742	2,418,000
1974......	−36,200	188,140	6,500	−18,814	139,626	2,558,000
1975......	−38,300	198,230	7,000	−19,823	147,107	2,705,000
1976......	−40,550	208,110	7,000	−20,811	153,745	2,859,000
1977......	−42,800	220,000	7,000	−22,000	162,200	3,021,000
1978......	−45,200	230,000	7,000	−23,000	168,800	3,190,000

[a] *Monthly Labour Review*, U.S. Department of Labour, Bureau of Labour Statistics, p. 1262, November 1966.

[b] "Projections of Educational Statistics to 1975–76", U.S. Department of Health, Education and Welfare, 1966. Including engineering, mathematics and statistics, physical and biological sciences, agricultural and forestry science and general science.

[c] "The Brain Drain into the United States of Scientists, Engineers and Physicians", A Staff Study for the Research and Technical Programs Subcommittee of the Committee on Government Operations, July 1967, Washington, D.C.

[d] That is, scientists and engineers leaving current stock of scientists and engineers in labour force and entering potential stock, counter balanced by the entrance into the science and engineering professions of people without a degree in science or engineering (many with no degree at all). Estimated as 10% of graduating class.

would be involved in R & D activities (in spite of the growth of the graduate schools), that the same percentage as the current level (33%) would be involved, and that 50 per cent would be involved. The first case might occur if the United States found its other commitments overwhelming (e.g. S.E. Asia) or if the international monetary problems continued. The second case represents a moderate expansion of present and potential programs, and the third case represents a further major expansion of large-scale R & D activity related to new major United States programs (e.g. oceanography, urban environment, post-Apollo programs). These three cases represent three separate growth rates of the number of scientists and engineers involved in R & D activities; namely, 1.9 per cent per annum, 5.9 per cent per annum and 9.3 per cent per annum, respectively (Figure 31).

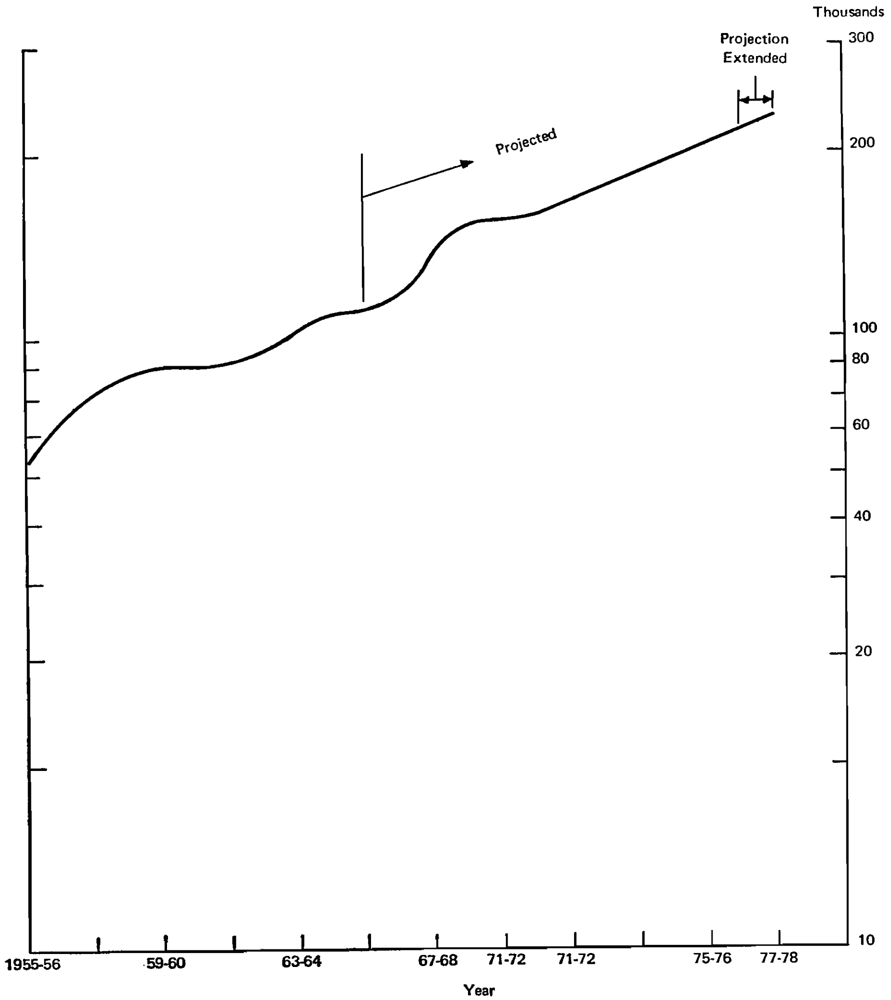
G.E.R.D.

In 1965, the gross expenditures on R & D in the United States amounted to $22,179 M[4] (3.2% of GNP). A "sophistication" factor of 3 to 4 per cent per annum is assumed in the cost of R & D per scientist and engineer (constant dollar terms), and the levels of G.E.R.D. in 1978 implied by the three different assumptions shown in Figure 31 are given in Figure 32 in 1965 constant dollars. The GNP for the United States in 1978 is projected, as a moderate value, to be $1230 B (1965 constant dollars).[5] Thus, if only 20 per cent of the scientists and engineers were involved in R & D in 1978, then the gross expenditures on R & D in the United States would be equivalent to 3.3 to 3.7 per cent of the GNP; if 33 per cent of the scientists and engineers, then 5.4 to 6.1 per cent of the GNP; if 50 per cent of the scientists and engineers, then 8.1 to 9.1 per cent of the GNP. Therefore, under relatively "normal" conditions, one would expect the United States G.E.R.D. as a per cent of GNP to rise in the future.

[4] "U.S. R & D Expenditures in 1967", a report from the Socio-Economic Section, Columbus Laboratories, Battelle Memorial Institute.

[5] H. Kahn and A. J. Wiener, *The Year 2000*, The MacMillan Co., New York, 1967, p. 159. Used as a growth rate of 4.5% per annum from the 1965 base.

Figure 29.—Science and Engineering Bachelor and First Professional Degrees Granted in U.S. Universities and Colleges



Source: "Projections of Educational Statistics to 1975–1976", U.S. Dept. H.E.W. Including Mathematics, Agriculture, Forestry; excluding Health Sciences.

Figure 30.—The "Current" Stock of Scientists and Engineers in the U.S. Labour Force to 1978

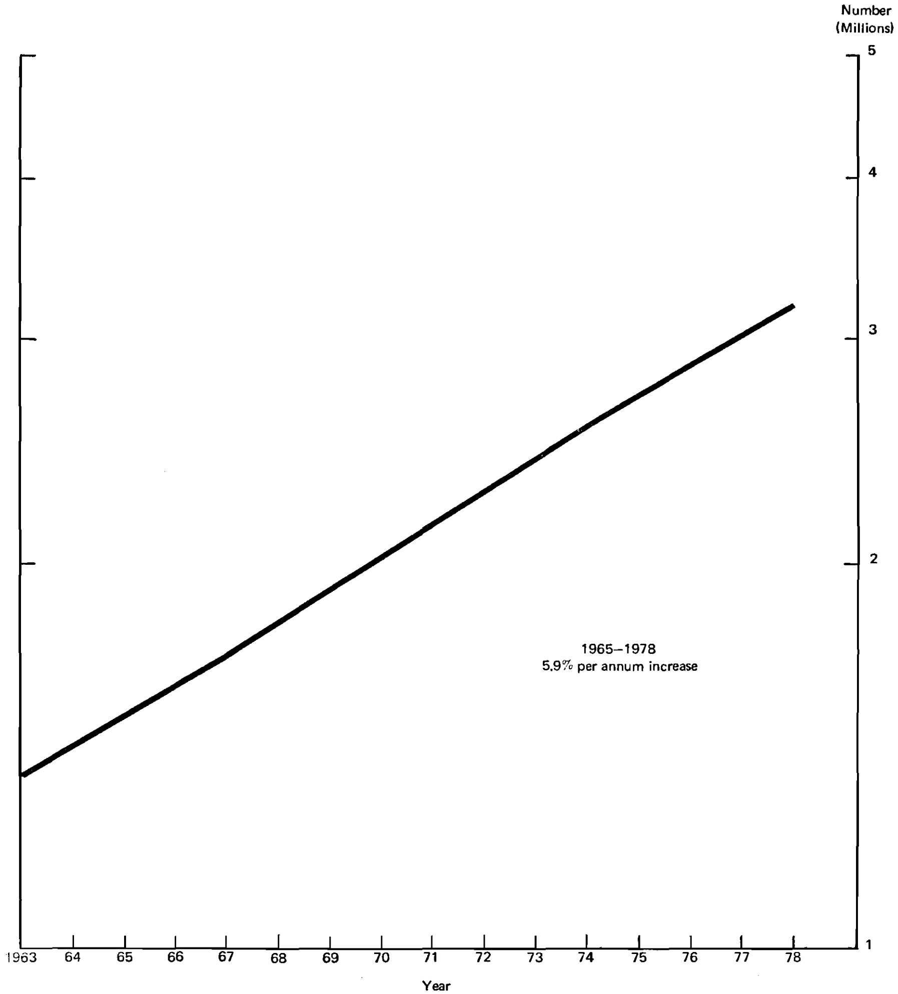


Figure 31.—Projections to 1978 of Scientists and Engineers (FTE) Engaged in R & D in the U.S.

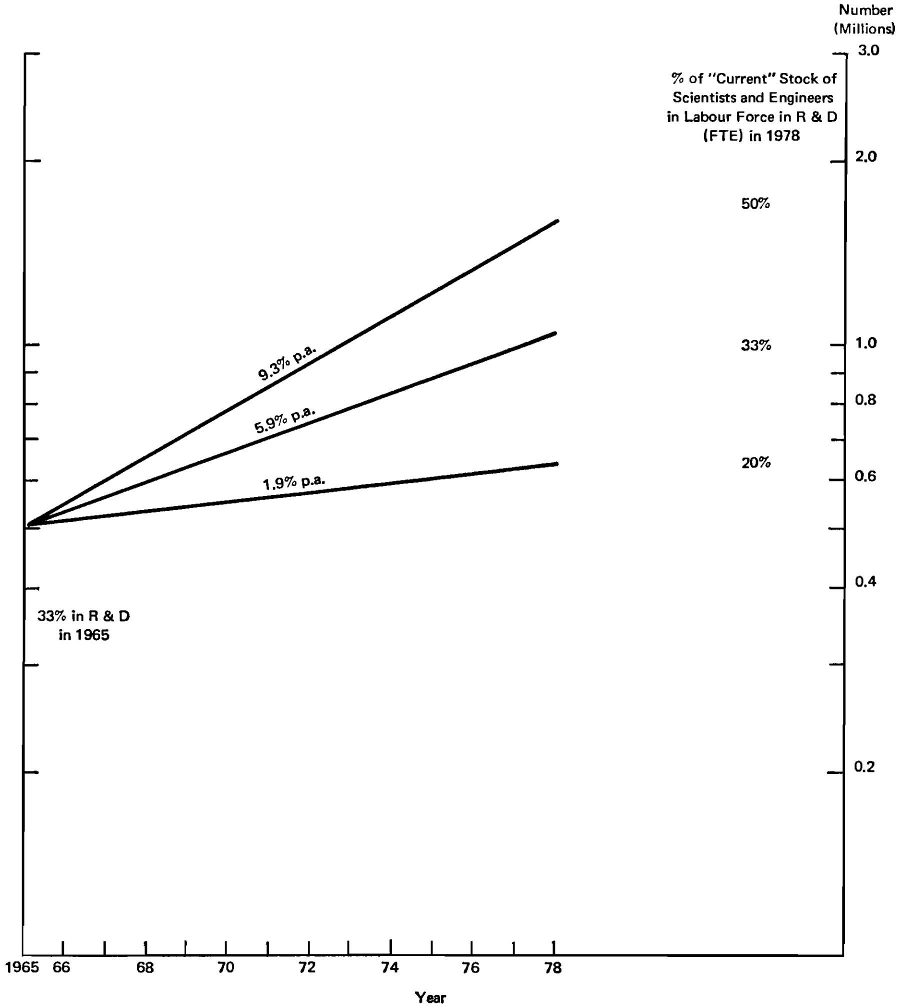
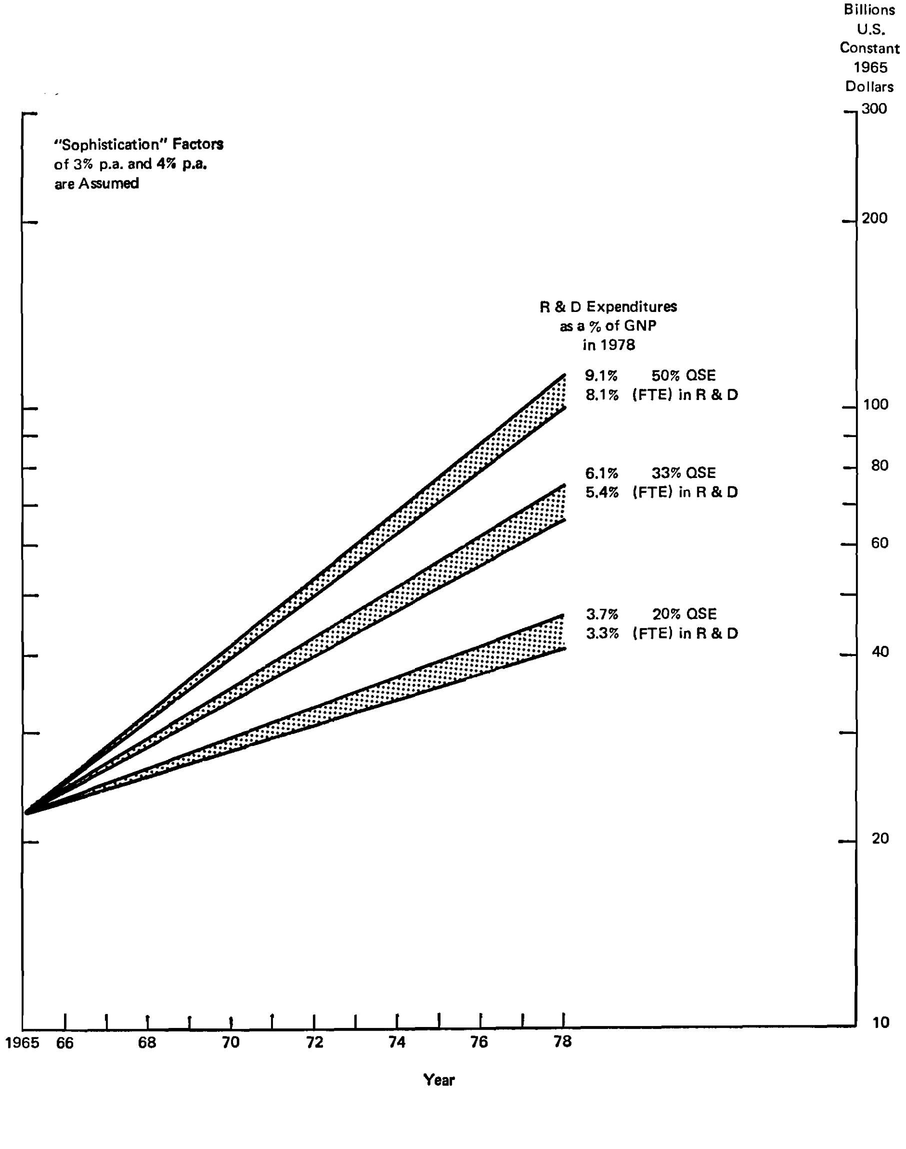


Figure 32.—Projections of G.E.R.D. to 1978 in the U.S.



A SUPPLEMENTARY NOTE

Comments by readers, and afterthoughts by the authors, since the texts of the foregoing Sections were first drafted have suggested that a supplementary note might be appropriate, and might help to avoid some misunderstandings or misinterpretations.

Because the scientist and engineer component of the labour force has been singled out for attention, there is some danger of generating a distorted perspective.

Thus, the projection implies an average growth rate of 8.2 per cent per annum (continuously compounded, or 8.6 per cent per annum compounded annually) over the decade 1968–78, while the labour force as a whole is projected to grow at less than 3 per cent per annum. From this one might leap to the conclusion that scientists and engineers are breeding themselves in excessive numbers, are going to usurp the entire labour force within the next half century, and something must be done to turn the process off.

But, it is not so simple. It is important to note that the scientific and engineering component of annual university graduations at the bachelor level is *only about 19 per cent of the total and is projected as a declining proportion over the decade of concern.*

Thus the rise in numbers of scientists and engineers projected is only an aspect of the total rise in educated level of the labour force. The total population with university degrees can be expected to grow if anything *more rapidly* over the next decade than the numbers of scientists and engineers. In what respect will this constitute an imbalance?

Of course, at that rate the entire population might approach university-degree level in 50 years, an outcome that few people are prepared to predict at this time. In fact, the Illing and Zsigmond projection of annual university output, on which the exercise was based, did not assume that such a rate of growth would be sustained and it shows, rightly or wrongly, a pronounced slowing down from about 1972 on.

Our understanding of the factors involved in industrial innovation, productivity, economic growth, and so on, leads us to realize that, rather than simply looking at the numbers of scientists and engineers, it would be much more meaningful to look at what is happening to the total *technostructure* of society. But the statistics have not yet been gathered which would allow an analysis along those lines.

We know, for example, that the *variety* of jobs for which engineering and/or scientific training is useful is growing as our society evolves industrially and technologically. We can suspect, therefore, that applying too narrowly circumscribed a definition of "engineering" can easily give rise to questions as to whether we are educating too many people for *those* jobs—questions which would point, not at real problems, but at pseudo-problems created by the way the questions are asked.

On the other hand, there is a sense in which there may be problems. The maintenance of nearly full employment has become accepted as a responsibility or goal of national economic policy. This policy must be expected to apply in the sector of the highly educated as well as in the sector of the unskilled. Do we understand well enough how the technological society functions, or will function in the future, to say how or by what policies a society achieves optimum utilization of its educated members, or even to say whether or not there is a problem? Could we be educating people at a higher rate than the economy can absorb? We know we have problems of mismatches here and there but, in macro-numbers, which this exercise is concerned with, it might be noted that even the growth projected will bring the educational level of the Canadian labour force after a decade only to about where the United States is *now*. At the present time, it is not in the educated sector that the United States seems to be experiencing its employment problems.

The underlying assumption of the previous paragraph is that education serves the economic goals of society—educated people *produce* more, and therefore it is to the society's interest to employ them in such ways as to gain the benefits from the educational investment. From another standpoint, however, it can be argued that a higher level of education is not so much a need of society, as a consumption by the individual of something from which he gains private satisfaction. If, even so, the first assumption still holds, the society that values the desires of individuals will try to exploit the output of the universities as a found resource; the society that places lower precedence on private desires will try to match supply to its economic growth expectations by controlling the supply; in either case a surplus of graduates relative to jobs available will be regarded as a waste—so much potential output foregone, with a social cost besides. On the other hand, if the first assumption is regarded as not true, or true only to a limited extent in specific sectors, the society will feel under no obligation to strive for optimum utilization of university output beyond what it considers to be its needs, and the cost of any surplus will be regarded as properly to be borne either by individuals as a private consumption expenditure or by the society as a burden in the nature of welfare. A third point of view, that of the extreme optimist, is that, while there may be shortages of high-level manpower, there will rarely be surpluses, since the individuals will tend to create their own employment.

These various philosophical beliefs lie like the sunken part of an iceberg under the assumptions and procedure used to develop the projections, and the different emphases which they have in people's minds will result in diverse reactions to the projections and diverse interpretations of their meaning for policy.

In view of all the uncertainties affecting the manpower projection—the reaction of demand upon supply, the exogenous economic and political vicissitudes, the diverse underlying beliefs that may determine policy—the projection may be open to criticism in presenting only one set of numbers rather than, say, high and low alternatives. However, while a mid-range projection, such as this attempts to be, suffers from the danger that it will be interpreted as an exact prediction, a presentation in terms of upper and lower "reasonable" bounds is not much better—the problem then is to choose the extreme assumptions so as to have some consistent degree of likelihood.

Turning to questions of gross national expenditure, the *employment* of this educated work force has certain economic implications. But, the fact that the scientists and engineers in the population are usefully and gainfully employed does not mean that there should be construed to be some vast integrated "Science Budget" any more than one would say there is a national budget for economics, or sociology, or for the efforts of salesmen. The significance of "Gross National R & D Expenditure" as an economic or social indicator must be understood in the right way.

It will be appreciated that the projections of gross expenditures on R & D are highly sensitive to the proportion of the scientists and engineers regarded as engaged in R & D and this, in turn, is highly sensitive to the *definition* used for R & D. The problem is that the nature of technical work in our society has not been constant and will not be constant. One might argue that the diffusion of science and technology through our society will mean in the future a greater variety of jobs requiring education in science, so that research will become only one activity among many, and R & D manpower could actually decline as a proportion of the whole. We have leaned, rather, to the view that science and technology have brought accelerating change over the recent decades, with the consequence that the work of scientists and engineers has been increasingly change-oriented, and therefore increasingly defined as R & D. We expect this trend to continue for some time. We make no apologies for this view, but admit that the semantics involved deserve a lengthier discussion than we can afford here.

The other important element in arriving at gross expenditures, besides the number of people employed, is the cost per person—in particular, in this field, the costs per engineer or scientist employed, and the escalation rate of those costs, or the inflation-sophistication factor. Again, one must be careful not to give an excessive special significance to this in the field of science and engineering. In manufacturing, in services, and in primary industry, the capital/labour ratio often changes drastically *because it is worth it* in terms of output relative to resources employed. As observed in Section 3, there is a dearth of analysis that would illuminate the point, but it is perfectly plausible that that is the true interpretation that should be placed on the "rising costs of research". (See, for example, Olaf Helmer, of the Rand Corporation, *Science Journal*, October 1967). In that event, one may be able to look forward to a flattening of the escalation, though probably not in this decade or the next.