DOCUMENT RESUME

ED 069 215 HE 003 537

AUTHOR	Skolnik, M. L.; McMullen, W. F.
TITLE	An Analysis of Projections of the Demand for Engineers in Canada and Ontario and An Inquiry into Substitution Between Engineers and Technologists.
INSTITUTION	Committee of Presidents of Universities of Ontario, Toronto.
REPORT NO	CPUO-R-70-2
PUB DATE	Nov 70
NOTE	77p.
AVAILABLE FROM	Secretariat of the Committee of Presidents, 230 Bloor Street West, Toronto 181, Ontario, Canada
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	Employment Opportunities; *Engineering Education; *Higher Education; International Education; *Job Market; *Manpower Needs

ABSTRACT

The first part of this report presents a comparative analysis of three studies of engineering manpower projections and a forecast of the number of engineering graduates required for Ontario to 1980. The projections are based on the extrapolation of past trends, but do not take account of major structural changes in the factors affecting the demand for engineers. One such factor may be the development and rapid expansion of the Colleges of Applied Arts and Technology and corresponding increased availability of technologists and technicians who might be substituted for engineers in some positions. Thus, the second part of the report presents the findings of an interview study of 16 firms that was designed to explore the question of substitution. In addition to the quantitative effects on the demand for engineers, it was desired to study the qualitative aspects, i.e., the type of work functions that graduate engineers are desired for and the speed with which they advance to higher levels. (HS)

Committee of Presidents of Universities of Ontario
Comité des Présidents d'Université de l'Ontario

An Analysis of Projections of the Demand for Engineers in Canada and Ontario

and

An Inquiry into Substitution Between Engineers and Technologists

by
M. L. Skolnik
and
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CPUO Report No. 70-2
November 1970

AN ANALYSIS OF PROJECTIONS OF THE DEMAND FOR ENGINEERS IN CANADA AND ONTARIO AND AN INQUIRY INTO SUBSTITUTION BETWEEN ENGINEERS AND TECHNOLOGISTS

By

M. L. SKOLNIK and W. F. McMULLEN

A REPORT SUBMITTED TO
THE COMMITTEE OF PRESIDENTS OF UNIVERSITIES OF ONTARIO
FOR THE STUDY OF ENGINEERING EDUCATION IN ONTARIO 1970-80

Supported by
The Canada Department of Manpower and Immigration
and The Ontario Department of Education
under the Manpower Training and Research Agreement
Project No. MTR-6-9

November, 1970.

PUBLISHED RESEARCH STUDIES BY THE COMMITTEE OF PRESIDENTS OF UNIVERSITIES OF ONTARIO RELATED TO THE STUDY OF ENGINEERING EDUCATION IN ONTARIO

(Available from the Secretariat of the Committee of Presidents, 230 Bloor Street West, Toronto 181)

CPUO Report No. 70-1	"Undergraduate Engineering Enrolment Projections for Ontario, 1970-1980," Philip A. Lapp. October, 1970.
CPUO Report No. 70-2	"An Analysis of Projections of the Demand for Engineers in Canada and Ontario and An Inquiry into Substitution Between Engineers and Technologists," M. L. Skolnik and W. F. McMullen. November, 1970.
CPUO Report No. 70-3	"A Method for Developing Unit Costs in Educational Programs," Ivor Wm. Thompson and Philip A. Lapp. December, 1970.

The Authors and Members of the Study Team

William F. McMullen, B.A.Sc., P.Eng., Manager, Recruitment and Manpower Planning, Bell-Northern Research, Ottawa, Ontario.

Michael L. Skolnik, B.A., B.Phil. (Oxon.). Lecturer in Educational Planning, Ontario Institute for Studies in Education

PREFACE

This report was done for The Study of Engineering Education in Ontario 1970-1980 (Committee of Presidents of Universities of Ontario), and some of the principal findings have been summarized in the complete study. This report was financed through a joint grant from the Canada Department of Manpower and Immigration and the Ontario Department of Education, and the Committee of Presidents of Universities of Ontario wish to express their thanks to the Hon. Otto Lane, Minister, Federal Department of Manpower and Immigration, and the Hon. W. G. Davis, Minister of Education of the province of Ontario, for making this study possible. The Committee wishes to express its thanks also to Northern Electric Company Limited and its President, Mr. V. O. Marquez, for contributing and making possible the services of Mr. William F. McMullen, Manager of Recruitment and Manpower Planning, Bell-Northern Research (formerly Northern Electric Research Centre), Ottawa.

The idea for this report was conceived by Dr. P. A. Lapp, Director of the Study of Engineering Education, and the study would not have been possible without the constant guidance, encouragement, and obstacle-clearing which he has provided. Considerable assistance in the early stages of planning the study was received from Mr. K. V. Pankhurst, formerly of the Department of Manpower and Immigration, Mr. Peter Ross of the Department of Manpower and Immigration, and Dr. R. C. Boyd of the Science Council of Canada. Thanks are due also to Professor Andrew Gross for his helpful suggestions. We are especially indebted to Mrs. Joan Barnes for her limitless patience in the role of typist and research assistant. The assistance of colleagues in the Department of Educational Planning of the Ontario Institute for Studies in Education has been as valuable as it is difficult to pin-point. Much of the capital which served in the production of this report was developed there, and many of the ideas presented here grew out of discussions with George Tracz, Madan Handa, Cicely Watson, Farid Siddiqui, John Hamwood, and Bill Dinan.

Lastly, and most importantly, we want to thank the many persons in industry who made this study exciting, rewarding, and meaningful, as well as possible. They extended pleasurable hospitality, and patiently answered all questions put to them, usually volunteering much more information than requested. In return for their co-operation, we have pledged them anonymity. We offer them our sincere thanks and the hope that this synthesis of our visits with them will not disappoint their expectations.

This is a report of a background study to *Ring of Iron: A Study of Engineering Education in Ontario* (Toronto: Committee of Presidents of Universities of Ontario, 1970). The views expressed herein are those of the authors and do not necessarily represent those of the Committee of Presidents of Universities of Ontario.

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INTRODUCTION

This report is divided into two parts.* The first part consists of a comparative analysis of three studies of engineering manpower projections. On the basis of this analysis, a forecast is made of the number of engineering graduates required for Ontario to 1980.

These projections are based on the extrapolation of past trends and as such, they do not take account of major structural changes in the factors affecting the demand for engineers. One such factor may be the development and rapid expansion of the Colleges of Applied Arts and Technology and corresponding increased availability of technologists and technicians who might be substituted for engineers in some positions. Skill substitution has been investigated very little, and there was no empirical basis upon which to assess the extent to which substitution of technologists for engineers is likely to occur in response to changes in relative supplies.

Because it was felt that this factor might have important implications for trend projections of the engineering manpower requirements, an interview study of sixteen firms was designed to explore the question of substitution. The methodology and findings of this study, as well as the implications for manpower projections are reported in Part 2.

In addition to the quantitative effects on the demand for engineers, it was desired to study the qualitative aspects as well; e.g. on the type of work functions that graduate engineers are desired for and the speed with which they advance to higher levels of responsibility. It

* Mr. M. L. Skolnik bears sole responsibility for Part 1.

was hoped also that this study would provide some insight into the philosophy, policies and institutional structures affecting the firm's decisions about the hiring, training, and utilization of engineering and scientific manpower. Finally, since empirical research on skill substitution has proved so difficult, it was hoped that the present inquiry would serve as a pilot project for assessing the usefulness of this methodology in shedding light on the process of skill substitution.

PART 1

PROJECTING THE DEMAND FOR ENGINEERS IN CANADA AND ONTARIO

A COMPARISON OF THREE STUDIES

SUMMARY

On the basis of a comparative analysis of three previous studies of engineering manpower requirements, projections of the required number of engineering graduates in Ontario to 1981 were made. The best projection was felt to be an average of 1,500 graduates per year during 1968-81.

The principal assumptions underlying this projection were:

(1) The real Gross National Product of Canada grows at a compound annual rate of 4% per annum.

(2) Engineering manpower requirements in Canada grow at approximately the same compound annual rate as GNP.

(3) The average annual rate of attrition of the stock of engineers during the projection period is just under 2% of the base year stock, the same for Ontario and Canada.

(4) The engineering manpower requirements in Ontario grow at the same rate as for Canada.

(5) Ontario's net gain of engineers through inter-provincial migration and through receiving a disproportionate share of engineers who immigrate

to Canada is slightly less than during 1951-61; i.e. Ontario must produce a slightly greater proportion of its engineering requirements than in the past.

(6) The number of engineers immigrating to Ontario from abroad is roughly equal to the number of Ontario engineering graduates who do not intend to practice engineering.

THE DIFFICULTIES OF COMPARISON

There have been three major attempts to forecast the requirements for engineering manpower in recent years, those of B. Ahamad[1] for the Canada Department of Manpower and Immigration (hereafter AMI), Noah Meltz and G. P. Penz,[2] also for the Department of Manpower (hereafter MAP), and Cicely Watson and Joseph Butorac[3] for the Ontario Institute for Studies in Education (hereafter WAB). The first two studies contain projections of the entire occupational structure for Canada, following an industry-occupation model similar to that of the OECD Mediterranean Regional Project.[4] The AMI study also included regional projections, derived from the national projections by assuming changes in the regional occupational distributions in each industry to be at about the same rate as the corresponding changes at the national level. The WAB study covered only Ontario; dealt with only professional, technical and skilled occupations, and employed a simpler methodology which did not include disaggregating by industry, but involved a deeper analysis of micro-level factors affecting professional employment and more extensive use of interviews than the other studies.

Different Time Periods

In addition to these general differences, three other factors make comparison of results difficult. First, the studies covered different time periods: AMI, 1961-75; MAP, 1961-70; and WAB, 1961-86. To make comparisons for the same period, say to 1980, the projections of the first two studies would have to be extrapolated, a task almost as large as the studies themselves. An alternative to compare the average annual required inflow, as in Table 2, may be misleading if trends in any of the relevant variables are not strictly linear, which is usually the case.

Differences in Definition

Secondly, the studies all used different definitions of engineer. AMI standardized by the 1961 census definition and MAP the 1951 definition. The treatment of the 'not stated' category of engineers differed in these two studies, and mining engineers were not included separately in the projections. In addition, AMI lumped surveyors in with civil engineers. While WAB avoided these difficulties, it used a 'qualification concept' and considered only those engineers with a university degree or some university (which excluded about 17% of the engineers in the 1961 census). MAP took account of this by assuming that all of the new entrants in engineering will have a university degree even if 28% of those enumerated in the 1961 census did not.

Since the initial stock is a crucial variable in a projection study, it is important to emphasize that all of these studies based their estimates of the 1961 stock of engineers on census data, as shown in Table 1. If the true stock of engineers were substantially above or below these estimates, the corresponding projections of required inflow would be biased downward or upward, respectively. In some ways the census estimate seems too high, because 28% of its engineers did not have a university degree, and the census engineers probably included many teachers, owners and managers. In 1961, in Ontario, the census showed 19,729 engineers, while the Association of Professional Engineers of Ontario showed 17,576 registered active professional engineers in Ontario.[5] Of course, many people working as engineers are not members of APEO (or other provincial associations of engineers); but, at the same time, many members do not practice engineering. Unless the former group is substantially larger than the latter, the census figure will not be an under-estimate.

Treatment of Attrition

The third complicating factor is that WAB (in Volume 1) have projected only required stocks and have not looked at attrition and required inflows.[6] In order to generate comparisons, the highest attrition of the AMI and MAP studies was applied to the WAB figures to generate projections of required inflow. All comparisons were made at the national level by applying the WAB projected compound annual rates of growth of the required stock of engineers in Ontario to the national stock, as shown in Table 2.

TABLE 1

BASIC STOCKS OF ENGINEERS, CANADA 1961
(Thousands)

	AMI Study[a]	MAP Study	Analog of WAB Study[b]
Chemical	3.0	3.0	2.8
Civil	11.9	11.9	10.8
Electrical	8.8	8.8	7.4
Industrial	4.0	4.0	2.3
Mechanical	8.1	8.1	6.3
Sub-Total	35.8	35.8	29.6
Mining	2.3	c	2.1
Engineers, n.e.s.	4.9	d	3.9
TOTAL	43.0	35.8	35.6

a Exact 1961 census figures, since 1961 census was basis for intercensal comparability.

b Obtained by applying the WAB 'qualification concept' for Ontario to the Canadian figures. Includes engineers with a university degree or some university.

c Not counted, but appeared in the 1951 census.

d Not counted since 1951 was the basis for comparability in MAP study and this category did not appear in the 1951 census.

TABLE 2

REQUIRED INFLOW OF ENGINEERS IN CANADA
(Thousands)

Study and Period	Base Year Stock	Terminal Stock Required	Net Increase in Stock	Compound Annual Growth Rate of Stock	Average Annual Rate of Attrition[a]	Attrition of Base Stock	Required Inflow	Average Annual Inflow
MAP[b] 1961-70	35.8	48.1	12.3	3.3%	1.27%	4.1	16.4	1.8
WAB 1961-71	35.6[c]	49.1	13.5	3.2%	1.27%[d]	4.5	18.0	2.0
AMI 1961-75	43.0	86.5[e]	43.5	5.1%	1.94%	11.7	55.2	3.9
WAB 1961-76	35.6	58.0	22.4	3.2%	1.94%[f]	10.4	32.8	2.3
WAB 1961-81	35.6	68.4	32.8	3.2%	1.94%[f]	14.2	47.0	2.4
AMI[g] 1961-81	43.0	116.4	73.4	5.1%	1.94%	17.1	90.5	4.5
MAP[g] 1961-81	35.8	68.6	32.8	3.3%	1.27%	9.1	41.9	2.1
MLS[h]	43.0	94.2	51.2	4.0%	1.94%	17.1	68.3	3.4

NOTES TO TABLE 2

[a] Attrition was calculated by MAP and AMI in terms of loss of the 1961 population; i.e. no account taken of attrition of those who enter the labour force after 1961. For convenience, this procedure has been followed in this review, although the inaccuracy introduced becomes greater as the forecasting period is made longer. Straight line attrition over time is assumed here.

[b] Since MAP standardized by the 1951 census definition the professional engineers, n.e.s., were not included in the base or terminal years. Neither were mining engineers, although they were listed separately in the 1951 census.

[c] The WAB figures were based upon the 'qualification concept' and included only engineers with a university degree or some university. They included mining engineers and engineers, n.e.s. The projected stock was obtained by applying the WAB estimate of the compound annual growth rate of the engineering stock for Ontario to the Canada base year stock.

[d] The WAB study (Volume 1) did not deal with attrition. The attrition rates estimated by MAP or AMI have been used to generate WAB projections of required inflow.

[e] The AMI alternative number 2 has been used throughout this review; it differs from alternative 1 by only about 1%. The AMI projections include surveyors with civil engineers. The figures in this review exclude surveyors by assuming equal rates of growth for surveyors and civil engineers.

[f] Assuming the highest attrition rate estimated from the other two studies.

[g] The projections are extrapolated by assuming a continuation of the same compound annual rate of growth of stock and average annual rate of attrition of base year stock as employed by the authors for the respective periods covered in the two studies.

[h] This is the author's projection, obtained by assuming that GNP grows at 4.0% p.a., that the demand for engineers grows at the same rate as GNP, and that attrition is at the rate forecast by AMI for 1961-75.

EXTRAPOLATING CANADA REQUIREMENTS TO 1981

The compound rate of growth of the demand for engineers projected by WAB is nearly identical to that projected by MAP, and is substantially less than the 5.1% by AMI. The latter study also assumes a 50% higher rate of attrition on the 1961 stock, adding to the gap between the projections.[7] In Table 2, the AMI and MAP projections have been extrapolated to 1981, assuming constant rates of growth of the number required and of attrition. The extrapolated projection of the required average annual inflow of engineers is 4.5 thousand for AMI compared to 2.1 for MAP, and 2.4 for WAB for the 1961-1981 period.

Relationship of Demand for Engineers to Growth of GNP

The data in Table 3 indicate the relationship between the growth of the stock of engineers and the growth of GNP. During 1951-1961, the stock of engineers grew at 3.5% per annum, while GNP grew at 3.6%, and actually higher if one adjusts for the cyclical differences between the two census years. The stock of engineers was clearly growing less rapidly than GNP.

For the period 1961-1981, population is forecast by the DBS to grow at a compound rate of between 1.2% and 2.0%. The lower right corner of Table 3 shows that at the higher rate of population growth and with GNP per capita increasing at a slightly faster rate than during 1951-1965, say 2.0% per annum, GNP would grow at a rate no higher than 4.0% per annum. If the rate of growth of GNP is no greater than 4%, then for the AMI forecast of engineers to be valid, the rate of growth of the demand for engineers would have to be substantially higher than the growth rate of GNP.

This suggested to the author a fourth alternative projection, labelled MLS in Table 2. The MLS projection assumes that GNP grows at a high rate, 4.0%; that the stock of engineers grows at the same rate as GNP; and that attrition continues at the higher AMI rate compared to the MAP rate. These assumptions generate a required

TABLE 3

COMPOUND ANNUAL RATES OF GROWTH
OF THE STOCK OF ENGINEERS IN CANADA
AND RELATED VARIABLES

	Actual	Projected		
	1951-61	1961-70 MAP	1961-75 AMI	1961-86 WAB
Chemical	1.5	0.7	3.9	2.0
Civil	4.4	3.4	5.5	4.0
Electrical	3.3	3.7	3.9	3.5
Mechanical }	3.8	3.6	5.3	2.8
Industrial }				3.5
Mining	1.4	a	a	0.0
TOTAL	3.5	3.3	5.1	3.2

			Projected from 1961-81			
	1951-61	1951-65	I	II	III	IV
GNP	3.6	4.4	3.4[b]	4.0[b]	2.9[b]	3.5[b]
Population	2.8	2.4	1.2[c]	2.0[c]	1.2[c]	2.0[c]
GNP/Capita	1.0	1.8	2.0[d]	2.0[d]	1.5[d]	1.5[d]

a Not projected separately.

b These are the compound rates of growth of GNP necessary to sustain the corresponding rates of population growth and of increase in GNP per capita.

c These are the highest and lowest of the twenty projected rates of population growth prepared by the D.B.S., <u>Analytical and Technical Memorandum No. 4: Population Projections for Canada, 1969-84</u> (Ottawa: April, 1970), Table A1, p.37.

d By assumption.

inflow of 3.4 thousand per year during 1961-1981.

ALTERNATIVE APPROACH TO COMPARING MANPOWER PROJECTIONS

In Table 3, the comparison of the AMI and MAP projections is in terms of the compound annual rates of growth of engineering manpower requirements in relation to the growth of GNP. Alternatively, the projected requirements may be related to other stock variables, such as labour force, or professional and technical employment, as was the methodology followed by the AMI and AMP studies. In the present context, it is most meaningful to relate the occupational projections to labour force or employment variables, since the occupational projections were made by projecting the total numbers employed and the occupational distribution of total employment separately.[8] It is instructive also to relate the projected employment in an occupational group (professional engineers) to the projection for the corresponding major division (professional and technical occupations) of which the former is a part. In some cases, the MAP occupational group projections were obtained by examining the trend in the occupational group employment as a proportion of the occupational division employment, and in both the AMI and MAP studies the sum of the group projections was constrained by the division total.

The requirements for engineering manpower can be expressed by the following relationship.

$$E = \sum_i \frac{E_i}{P_i} \cdot \frac{P_i}{N_i} \cdot N_i \qquad (1)$$

where E, P, and N denote engineering, professional and technical, and total employment, respectively. The subscript i refers to the i-th industry, and in terms of aggregates, equation (1) becomes

$$E = (E/P) \ (P/N) \ N \qquad (2)$$

Differences between the two studies in the projection of engineering manpower requirements can be attributed to corresponding differences in projections of:

(a) Aggregate employment.

(b) Distribution of employment by industry.

(c) Ratio of employment in professional and technical occupations to total employment, in aggregate and by industry.

(d) Ratio of employment in engineering to professional and technical employment, in aggregate and by industry.

Differences in Projections of Total Employment

Projected employment is shown in Table 4. A linear interpolation between the 1961 figure and the AMI 1975 projection of total employment (ALT-2) gives an estimate of 7,892 for 1970, which is within 0.1% of the MAP projection. Thus the difference between the two projections must be attributed to other factors.

Other Sources of Difference Between Projections

The projections of the two aggregate ratios of equation (2) are shown in Table 4. Direct comparisons between the AMI and MAP ratios are not relevant, since each study used a different basis for estimating engineering and professional and technical employment.[9] However, it is meaningful to compare the trends in these ratios between the two studies. To facilitate comparison, linear interpolations were made between the 1961 figures and the AMI 1975 projections.

The table indicates that AMI projected a greater increase in the ratio of professional to total employment, and a smaller decrease in the ratio of engineering to professional employment than in the MAP study. Both factors worked in the same direction, making the

TABLE 4

COMPARISONS OF EMPLOYMENT PROJECTIONS[a]

	(1) Total Employment (Thousands)	(2) Ratio of Professional and Technical to Total (%)	(3) Ratio of Engineering[b] to Professional and Technical (%)	(4) Ratio of Engineering to Total (%)
MAP				
Actual 1961	6049[c]	9.8	6.1	0.6
Projected 1970	7883	12.4	4.9	0.6
AMI				
Actual 1961	6049[c]	10.0	7.1	0.7
Interpolated 1970[d]	7892	13.7	6.5	0.9
Projected 1975	8914	15.7	6.2	1.0

a The figures in the two studies are on different classification bases. That is why the ratios differ between the first and third rows.

b Engineering Labour Force was used in 1961 instead of employment, but the discrepancy between the two was only about 1%.

c This is the D.B.S. Labour Force Survey figure, not the census figure, see MAP, Table 1, p.5.

d Linear interpolation between 1961 and 1975 figures.

AMI projection of engineering employment outstrip the MAP projection.

Three questions immediately arise:

(i) What is the relative importance of the differences between the two aggregate ratios in explaining the difference between the projections of engineering requirements?

(ii) To what extent can the differences in projections of the aggregate ratios be explained by differences in the projections of ratios for particular industries?

(iii) Which projections of the ratios, (P/N) and (E/P), appear to be most justifiable?

None of these questions is easy to answer. Most of the data required for (ii) and (iii) were not available, and analyzing (i) required converting employment figures in the two studies to a common base.

Following this conversion of data, application of a standard differential approach[10] indicated that the discrepancy in projecting the ratio of engineers to professional and technical employment, (E/P), accounted for about twice as much of the difference between projections of engineering employment as did the discrepancy between the projections of the other ratio, professional and technical to total employment, (P/N). Unfortunately, the data required for assessing the importance of differences in projected industry structure in explaining differences in the projection of the aggregate ratio of engineering to professional and technical employment were not available. It was possible, however, to estimate the effect of differences in the projection of industry structure on differences between the projections of the less important factor (P/N). The conclusion here was that the difference between the AMI and MAP projections of aggregate (P/N) centered mainly on the services and public administration sectors. Taken together this was the largest industry (about 30% of employment in 1966), and it had the highest ratio of professional and technical to total employment.

AMI projected both a substantially faster rise in this industry's share of total employment and a greater increase in its professional and technical group than did MAP.

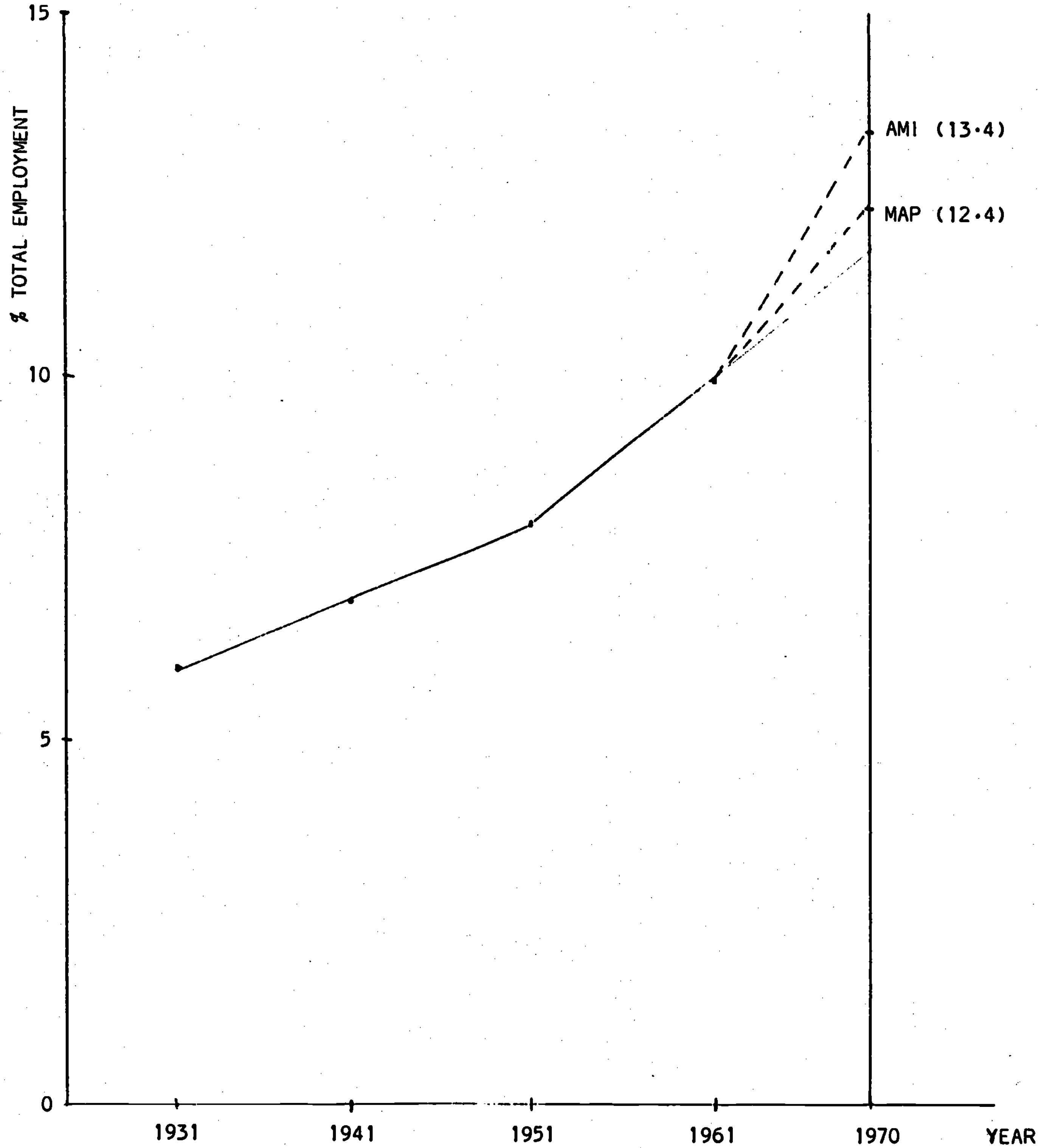
To answer the third question it is necessary to examine the trends in the ratios, E/P and P/N. The ratios of professional and technical to total employment, from the census data are plotted in Figure 1, along with the MAP and AMI projections to 1970. The AMI figure, 13.4%, was obtained by converting the interpolated estimate to the same base as used by MAP.

In both studies the projections of P/N were made in a discretionary manner by visually fitting lines through the census ratios by industry (MAP) or through the logarithms of the census occupational division totals by industry (AMI). Adjustments were then made to insure that the sums of the ratios across all occupation divisions were equal to unity within each industry, and to take account of such other qualitative data (e.g. judgement of experts) as was available.

These data show that the MAP projection for 1970 is relatively near the straight line through the 1951 and 1961 ratios. A projection which allows a slightly steeper slope for the 1961-1970 segment compared to the 1951-1961 segment is equally defensible, since the latter was steeper than the 1931-1951 segment. A slightly higher projection would be obtained by fitting a line through the logarithms of the ratios, and this was in fact the procedure followed by AMI. Alternatively the AMI projection could have been higher than the MAP projection as a result of some qualitative judgement

FIGURE 1

PROJECTIONS OF THE RATIO OF PROFESSIONAL AND TECHNICAL TO TOTAL EMPLOYMENT



Source: MAP, Figure 3, p. 19.

The AMI projection from AMI, Table 7-3, p. 139.

not mentioned specifically in the text. At any rate, both projections of P/N are justifiable, and it is impossible to choose between them. If one were to take the mid-point between the two projections, 12.9%; then with the MAP projection of E/P, the implied compound rate of growth of engineering manpower requirements would be 3.8%.

Both studies project a decline in the value of the other ratio, E/P. The AMI projection for 1970 on the MAP base is 5.6%, compared to the MAP projection of 4.9%. Taking the mid-point, 5.25% along with the mid-point between the two projections of P/N, would give a compound rate of growth of engineering employment requirements of 4.6%. Unfortunately, neither study presented the data which would be required to examine the trend in the E/P ratios. Thus, while it is possible to assess the extent to which differences in the projections of P/N and E/P account for differences in the projections of E, it is impossible to second-guess these two studies on their projections of the two ratios. Taking the mid-points between the projections of these ratios gives an implied compound rate of growth of engineering employment half a percent higher than the 4% suggested earlier by the author, but there is nothing scientific about taking mid-points. While the author continues to lean toward the 4% figure, the difficulty of making precise projections should be borne in mind. For that reason, results in this review will be presented in terms of a range from the most conservative to the most optimistic projections.

UPDATING THE 1961 BASE

It is unfortunate that in 1970, projections relying on census data must be made from a 1961 base. In partial remedy, some data is available on potential net increments to the stock of engineers during 1961-68. Table 5 shows that 17.2 thousand first degrees in engineering were awarded during this period and that 8.8 thousand immigrants intended to go into engineering net of emigration of engineers to the United States (but not other destinations). Subtracting this potential net addition of 26 thousand engineers from the 1961-81 required inflow, gives projections of the required inflow for 1968-81, shown in the last two rows of Table 5. These range from 1.4 thousand per year according to the WAB-MAP projections to 5.0 thousand by the AMI projection, with the MLS about half way between.

It might be argued that the 26 thousand estimated potential net inflow during 1961-68 is an over-estimate, since some of those receiving first degrees in engineering went on to graduate school and some immigrants 'intending' to work as engineers may not actually have done so. Yet, the new graduates eventually will join the labour force, probably before 1981. Similarly, the immigrants who did not go directly into engineering are nevertheless potentially available. The crucial question with regard to both domestic graduates and immigrants is the extent to which their decisions to go into engineering are based on market conditions. To the extent that these decisions are independent of market conditions, the full potential increment to the stock of practicing engineers will never be realized. Such figures should not be included in the 1961-68 net inflow; moreover the number of graduates turned out will have to be

TABLE 5

PROJECTING REQUIRED ENGINEERING MANPOWER INFLOW

FOR CANADA TO 1981
(Thousands)

	WAB-MAP	AMI	MLS[c]
1. Required Inflow 1961 81.			
Total	44.5	90.5	68.3
Annual Average	2.2	4.5	3.4
2. Bachelor's Degrees[a] in Canada, 1961-68.			
Total	17.2	17.2	17.2
Annual Average	2.5	2.5	2.5
3. Net Immigration to Canada[b]			
Total	8.8	8.8	8.8
Annual Average	1.3	1.3	1.3
4. Required Inflow 1968-81 (equals (1)-(2)-(3))			
Total	18.5	64.5	42.3
Annual Average	1.4	5.0	3.3

a Z. E. Zsigmond and C. J. Wenaas, Enrolment in Educational Institutions by Province, 1951-52 to 1980-81, Staff Study No. 25 (Ottawa: Economic Council of Canada, January 1970), Table B-21, pp.188-89.

b A. G. Atkinson, K. J. Barnes, and Ellen Richardson, Canada's Highly Qualified Manpower Resources (Ottawa: Department of Manpower and Immigration, 1970), Appendix Table 1.9, p.202. The net immigration is over-estimated to the extent that it covers emigration only to the United States. On the other hand, the immigration figures pertain to immigrants who record 'engineering' as their intended occupation.

c See note h to Table 2.

larger than the required inflow to take account of those who have no wish to pursue engineering regardless of the market for engineers, or alternative opportunities; e.g. secondary shool teachers. Since there is no information on the career preferences of new graduate engineers, no adjustment of this kind has been made in Table 5. There is equally little known about the extent to which immigrants' occupation intentions are realized. However, one-third of the engineers in the 1961 census were immigrants, the same as the immigrant proportion of potential additions to the stock of engineers during 1961-68.

ENGINEERING MANPOWER REQUIREMENTS FOR ONTARIO

Table 6A shows that the number of engineers in Ontario has ranged from 45% to 50% of the total for Canada since 1941 and that about 35% of bachelor's degrees in engineering awarded in Canada have been in Ontario. These two facts taken together suggest that Ontario has been receiving - (a) a positive net interprovincial migration of engineers and/or (b) a disproportionate share of immigrant engineers. The evidence available suggests that (a) is the main factor. According to the 1967 manpower survey, about one-third of Canada's engineers and scientists resided then in a different province from the one in which they received their secondary school education. Ontario received 42% of the movers, which was a net gain of 91% over the number who had completed secondary school education in Ontario[11]. On the other hand, Ontario was the destination for about 45% of the immigrants to Canada during 1957-62 who gave engineering as their intended occupation, and about 48% during 1963-69[12]. AMI derives Ontario projections for 1975 from the national projections by assuming that the

TABLE 6

REQUIREMENTS OF ENGINEERING MANPOWER IN ONTARIO

A. Percentage of Canada's Engineers and Bachelor's Engineering Degrees in Ontario for Selected Years 1941-1968.

	1941	1951	1952	1955	1960	1961	1965	1968	Average 1961-68
Census Stock of Engineers Canada/ Ontario	50.3	49.3	X	X	X	45.8	X	X	X
Bachelor's Degrees Canada/ Ontario	X	X	37.2	32.9	31.4	30.4	34.8	39.7	35.1

B. Projected Required Inflow of Engineers in Ontario (assumed 35% and 46% of requirements for Canada).

	WAB-MAP		(Thousands) AMI		MLS	
	At 35%	At 46%	At 35%	At 46%	At 35%	At 46%
Total 1968-81	6.5	8.5	22.6	29.7	14.8	19.5
Annual Average	0.5	0.6	1.8	2.3	1.2	1.5

Sources: Same as for Table 5.

Ontario proportion of the national stock will remain about the same as in 1961, and this seems a reasonable approach. This would mean that about 46% of the net increase in Canada's stock of engineers up to 1981 should reside in Ontario in 1981. If there were zero net interprovincial migration of engineers to Ontario and the provincial distribution of immigration of engineers was according to the 1961 distribution of the stock; i.e. Ontario got about 46% of immigrants to Canada, regardless of the total; then Ontario would have to produce and/or receive from immigration 46% of Canada's required net inflow in order to retain its 1961 share. To the extent that the positive net gain from other provinces continues, Ontario can produce and/or receive from immigration less than 46% of the required net inflow (subject to the influence of changes in the provincial distribution of immigrant engineers). However, as a consequence of the narrowing of regional disparities in Canada, the poorer provinces may retain more of their engineering graduates and attract a greater share of immigrants; and Ontario may have to produce more of its own qualified manpower than previously[13]. The upshot of this discussion is that Ontario should produce between 35% and 46% of the number of engineering graduates required for Canada up to 1981, less what it receives from immigration - with the exact figure depending upon what assumptions one makes about the distribution of immigration and about interprovincial migration. In Table 6B, alternate projections of the required net inflow of engineers for Ontario are derived by taking 35% and 46%, respectively, of the corresponding Canada totals in Table 5.

The projections of average annual requirements range from a low of about 500 per year for WAB-MAP at 35%, to a high of

2,300 for AMI at 46%, with MLS at 46% in between, about 1,500. Only if there is zero net immigration and all new graduates are willing to go into the engineering labour force (even if some go to graduate school first) can these figures be interpreted as requirements for the number of engineering graduates. Of course, there probably will be positive net immigration, and some loss of engineering graduates from the profession and there is no reason to believe that these effects will cancel each other. However, immigration has averaged about half as much as the annual number of bachelor's degrees, and it is doubtful that the loss of new graduates from the profession is that large[14]. This fact, together with the high rate of growth of the demand for engineers assumed in the AMI forecast make the 2,300 figure look like an extreme upper limit for the annual requirements of bachelor engineering graduates. The conclusion of this review is that on the basis of past trends the number of graduates per year required for Ontario during 1968-81 is not likely to be above 1,500.

FINAL QUALIFICATIONS

Four qualifications are necessary. First, the required inflow projections in this review labelled WAB, MAP and AMI, are the logical result of applying certain assumptions about the rate of growth of the demand for engineers in Canada, attrition, the stability of the Ontario share of the Canadian engineering stock, rate of population growth, immigration rates and other factors. The label indicates that at least one, but not all, of the principal assumptions underlying a particular forecast has been used in the corresponding study and the projection should not be construed as completely representing the work of the labelled study. In the opinion of this reviewer, the labelled projections in Tables 2-6 are broadly consistent with the corresponding studies, but those authors should bear no responsibility for the interpretations, extensions and extrapolations of them made in this review.

Data not Disaggregated by Degree Level

Secondly, no distinction was made between requirements for first degrees in engineering and requirements for post-graduate degrees, since the census data do not provide this breakdown. This is a serious limitation, for it should not be assumed that the numbers demanded at each of the two (or three) levels of training are growing at the same rate. The interviews with employers conducted by the authors mainly for the second part of this monograph indicated that firms were having a much easier time filling their needs for engineers with master's and doctorate degrees than for engineers with first degrees. Although this question lies outside of the scope of an analysis of the above manpower forecasting studies it is clearly of great importance, particularly because of the rapid growth of graduate training in engineering in recent years.

Projections Based on Extrapolation of Past Trends

Thirdly, in these, as in most manpower forecasts, the methodology consists mainly of extrapolating past trends. Obviously such projections do not take account of major structural changes that make for discontinuity between present and future. One such factor may be the development and rapid expansion of the colleges of applied arts and technology and corresponding increased availability of technicians and technologists, who might be substituted for engineers in some positions. However, a study conducted by this reviewer and Mr. W. F. McMullen (summarized in the following part of this monograph) concludes that the 'pure supply effects' have not been important, and the desired mix of technologists and engineers has depended mainly on technology rather than upon relative wages. As such, it does not seem crucial to temper the manpower forecasts for the effect of the expansion of the CAATs. However, when technological change is rapid and discontinuous, the smooth extrapolation of past trends in variables greatly affected by the state of technology is hazardous. Likewise, other changes; e.g. a major shift in the public's willingness to spend on pollution control could invalidate the extrapolation of past trends.

The Meaning and Use of Manpower Projections

Finally, it should be noted that the purpose of manpower forecasting is to provide an estimate of the minimum number in each category of qualified workers without which the functioning of the economy would be impaired seriously. The Canadian economy is quite flexible and can adjust to wide variations in the number of graduates turned out in any particular field. Theoretically, it is likely that there is some minimum number below which production would suffer or costs would rise sharply; and some maximum above which graduates would have a difficult time finding employment commensurate with their skills without considerable further training. In normal times, such points are rarely encountered. The purpose of estimating the minimum level of qualified manpower requirements is that such education is generally costly, and the more the number of graduates is increased beyond this minimum the less are the costs justified solely in terms of economic return.

However, there are a number of sound reasons for carrying the production of gradutes beyond this minimum, not the least of which is a fear of under-estimating the minimum. A wide educational base makes possible the selecting of the most talented, and in a highly specialized economy, the best matching of individuals with jobs. In a technologically oriented society, an engineering education appears increasingly to be less vocationally directed and more of a general education. Finally, a wealthy country can, up to a point, afford to provide students with the opportunity to pursue the courses of their choice. The situation where forecasted engineering enrolments exceed the minimum estimates of manpower requirements is far more pleasant and easier to cope with than the opposite situation.

NOTES

1. B. Ahamad, A Projection of Manpower Requirements by Occupation in 1975, Canada and its Regions (Ottawa: Department of Manpower and Immigration, 1970).

2. N. Meltz and G. P. Penz, Canada's Manpower Requirements in 1970 (Ottawa: Department of Manpower and Immigration, 1968).

3. C. Watson and J. Butorac, Qualified Manpower in Ontario 1961-1986. Volume 1: Determination and Projection of Basic Stocks (Toronto: Ontario Institute for Studies in Education, 1968).

4. See R. G. Hollister, A Technical Evaluation of the First Stage of the Mediterranean Regional Project (Paris: OECD, 1966).

5. WAB, p. 68. This excludes 1,733 members residing outside of Ontario and 875 who did not practice their profession due to retirement or other reasons.

6. Attrition is dealt with in the forthcoming Volume 2.

7. Much of the difference between the two projections of attrition rates appears to be due to the fact that the AMI projection covers a longer time period.

8. On this point, AMI contains an excellent discussion of the advantages of forecasting the occupational distribution rather than making direct projections of employment by occupation (pp.35-37). Likewise MAP obtained employment by industry making separate projections of total employment and industrial distribution. AMI forecast output and productivity directly and for each industry, and noted that the projected sum of employment across industries was consistent with the Economic Council's labour force projection (W. M. Illing, M. V. George, Y. Kasahara, and F. T. Denton, Population, Family, Household, and Labour Force Growth to 1980, Staff Study No. 19 (Ottawa: Economic Council, 1967) when the upward revision of DBS population projections is taken into account (M. V. George and K. S. Gnanasekaran, 1966 Census Data and Recent Population Projections for Canada, Technical Memorandum, Population Estimates and Projections, Series No. 2 (Ottawa: DBS, 1968).

9. The total employment is the annual average civilian employment taken from Table 1 of the MAP study, p. 5.

10. For a thorough discussion of the simple but often abused method, see R. G. Hollister, A Technical Evaluation (cited in note 4), pp. 53-55.

11. A. G. Atkinson, K. J. Barnes, and Ellen Richardson, Canada's Highly Qualified Manpower Resources (Ottawa: Department of Manpower and Immigration, forthcoming).

12. Annual Reports of the Department of Manpower and Immigration.

13. This remark is highly conditional. Disparities may not be narrowed or the poorer provinces may advance through kinds of development that necessitate proportionately less highly qualified manpower than Ontario has required; e.g. through the use of 'intermediate technology'; or the expansion of engineering education in the poorer provinces may outpace even gap-reducing growth; and so forth.

14. If about one-third of the net inflow comes from immigration, and all graduates go into engineering, then the MLS projection would be just over 1,000 per year.

PART 2

AN INQUIRY INTO SUBSTITUTION BETWEEN ENGINEERS AND TECHNOLOGISTS AN INTERVIEW STUDY OF SIXTEEN FIRMS

SUMMARY

by W. F. McMULLEN

Part 2 of this study has been written from an economist's point of view and this interviewer felt that a short summary of impressions from the industrial point of view might be of interest.

The study produced answers at variance with what this team member expected.

Professional Registration

Very few of the firms really required professional registration of their engineers and in fact most firms did not know which of their engineers were registered. Professional certification in itself seemed to have almost no impact on substitution. Professional organization within the firms generally acted as a barrier to career and educational substitution, and also provided a clear line of demarcation in some cases between union and non-union employees. Some professional groups seemed to have a vested interest in opposing the growth of the technologist.

There is undoubtedly social resistance (or the "iron ring" ethic) as well.

Management Attitude

Technologists were almost never regarded as career substitutes for engineers. In many firms engineers were hired particularly for their management potential. In some firms it was apparent that only engineers would be hired even when there was no indication that they would ever practice engineering.

There are no strong financial incentives for substitution, and the increased availability of technologists is likely to have little impact.

While only one firm apparently has completed an in-depth study of utilization involving replacement of engineers by technologists, it appears that there are some reservations held by management. As the study shows such substitution is most likely to occur through maturation of a technology, introduction of computer technology, or a process change. In fact most examples of substitution of technologists were not only dependent upon simultaneous changes in technology but also involved a functional reorganization of the engineer's work. It appears easier to down-grade the position than up-grade the technologist.

As a final comment the relative demand for engineers and technologists appeared to be influenced mainly by the state of the technology and very little by the relative availability of engineers and technologists.

In the opinion of the interviewers, substitution would be carried to anywhere near its extreme potential only if there was a drastic reduction in the absolute number of graduate engineers turned out in spite of however great the expansion of the diploma technology program might be.

THE STUDY OF SKILL SUBSTITUTION

Substitution between different occupational or educational categories has been a neglected topic in the field of manpower economics. There are two principal reasons for this neglect.

First, it has been conceptually simpler and operationally expedient in economic model building to assume that skill requirements are determined by technology and that substitution between different occupational or educational categories is impossible. This assumption is basic to the most well-known economic models relating output to the structure of the labour force.[1] The use of this assumption has been criticized, and there has been at least one attempt to construct an economic model which allows for substitution in response to changes in relative wages.[2] Critics have argued that the degree of skill substitutability in the economy (i) is an empirical question on which there is little evidence; and (ii) has vital implications for educational and manpower planning. Professor Blaug has shown that in general the greater the substitutability, the more difficult - but at the same time the more urgent - is the task of projecting manpower requirements.[3]

Difficulties of Empirical Analysis: The Econometric Approach

The second, and probably more important, factor accounting for the neglect of this question has been the difficulty of empirical analysis. While there is a vast literature on econometric analysis of aggregate labour-capital substitution in the two-factor production function, there have been few econometric studies of substitution between different categories of labour in the n-factor case (where $n \geqslant 3$). Considerable statistical estimation problems arise when one attempts to fit a production function with more than two factors, and ordinarily the data for such an undertaking are inadequate, particularly as concerns the way the different categories of labour are defined. The results of attempts to estimate skill substitutability through production function analysis have not been encouraging to date.[4]

An econometric approach based on the use of derived demand equations shows more promise than direct estimation of the production function, and it has been used by one of the authors in a previous study of substitution between engineers and technicians.[5] The derived demand study was constrained by strong assumptions and weak data. The results appear to be at odds with those of the present interview study, and the apparent discrepancy in findings is discussed in the concluding section of this report.

The Case Study Approach

The principle alternative to an econometric study of substitution is the case study or interview approach.[6] This type of approach can range in depth from merely putting a simple question to a representative of the firm, to an intensive probing of hiring, promotion, supervision, and utilization of manpower within the firm. Neither the simple questionnaire nor the more intensive "field work" approach are held in high repute among economists generally.

Some Pros and Cons

A thorough analysis of the pros and cons of the econometric approach vis-a-vis that of questionnaires and interview requires a detailed study of social science methodology and the philosophy of knowledge - which is beyond the scope of this inquiry. However, a few of the main points should be noted.

Critics of the interview technique stress the communication gap between the economist and businessman and the difficulty for the latter to articulate his behaviour in the language of the former. Professor Machlup, the undisputed leading critic, has argued that the explanation of the businessman's behaviour "must often include steps of reasoning which the acting individual himself does not consciously perform (because the action has become routine) and which perhaps he would never be able to perform in scientific exactness (because such exactness is not necessary in everyday life)."[7]

Though some of the criticisms of the simple questionnaire approach are valid, the depth interview - particularly when supplemented by extensive observation and access to relevant quantitative data - would seem to overcome most of the traditional objections (except generalizability). In any case, there are advantages and disadvantages for each type of method, and the two approaches need not be looked upon as being mutually exclusive.

The case study approach can serve a useful and often neglected role in generating new hypotheses.[8] It can provide fresh insight into a complex problem, which enables a more rigorous delimitation and definition of variables to be analyzed later within the frame work of an econometric model. With regard to many questions in the social sciences, theory has not yet progressed to the stage where an econometric model can be devised; and the existing base for such a model may be inadequate. In these situations, the case study approach can stimulate further development of theory, indicate the kind of simplifying assumptions upon which an econometric model might be based, and suggest the type of data which should be collected. It was particularly with these goals in mind and in view of the little progress that had been made in the econometric analysis of skill substitution that the present interview study was undertaken.

Beyond these complementarities between the two approaches, the case study method is valuable in its own right as an alternative source of data so that of econometric estimation. It is interesting and important to know how employers perceive their manpower decisions - even if, as Professor Machlup suggests, they do not behave as they say, or think, they behave. Behaviour is likely to be influenced more by what the constraints are perceived to be than by actual constraints.

Moreover, the econometric approach, even with ideal data and statistically meaningful results, is not without its problems of interpretation. A few critics have stressed that no amount of ex-post data can prove the existence of an ex-ante menu of choices from which employers choose factor combinations in such a way as to minimize costs. On this point, it is worth quoting Joan Robinson's remarks in a recent issue of the Canadian Journal of Economics.[9]

> "Statisticians, though with a very coarse mesh, can catch evidence of the capital output ratio in terms of dollar values, and the shares of wages and profits in value added, over a particular period in a particular economy, and so they can offer an estimate of the ex-post, over-all rate of profit being realised. They cannot say what expectations of profit were in the minds of the managers of firms or whether alternative schemes were on the drawing boards of engineers, when the investment decisions were taken that brought a particular stock of capital equipment into existence. Still less can they say what decisions would have been taken if present and expected prices and wage rates had been different from what they were."

METHODOLOGY OF THIS STUDY

Having attempted to provide the rationale for the type of study undertaken, a brief description of the methods used is in order. The study consisted mainly of interview sessions with sixteen organizations which employ large numbers of engineers. The interviews were conducted by the authors and were centered around questionnaires that had been developed in co-operation with a number of experts in the field of engineering manpower, including representatives of the Canada Department of Manpower and Immigration, The Science Council of Canada, and the Committee of Presidents of Universities of Ontario. The interviews yielded considerable quantitative data on engineering and scientific manpower, as well as policy, opinion, and illustration from numerous respondents in different positions within each organization. Mr. McMullen's experience in the field of engineering manpower recruitment and personnel was a major asset for the study team in getting to the appropriate people, establishing good rapport, directing the discussion, and interpreting the comments of the interviewees.

The Questionnaires

There were two questionnaires. Questionnaire I asked for information on the current numbers of engineers, scientists and technicians/technologists by type of education and work function; and the numbers of additions and separations during the last two years. This questionnaire was sent out with an explanatory letter in advance of the interview, and in most cases the data were provided before the interviews. Four of the sixteen firms were unable to complete this questionnaire, but three of these were small firms which provided some information on relative numbers in the different categories and on recent trends.

Questionnaire II was also sent out in advance, but only to give respondents a general idea of the type of questions that the study team wanted to discuss. This questionnaire was then used as a guide in the interviews. Not all questions were asked of every respondent, and in many areas the discussion went much deeper than indicated by a particular item on the questionnaire. In general, the interview sessions were loosely structured, and all promising avenues were followed up.

In most organizations, at least three people in different areas of responsibility were interviewed. The study team sought as respondents those with responsibilities for: (1) engineering and scientific manpower recruitment; (2) engineering and scientific manpower salary administration; and (3) management (especially at a level including technical supervision) of an operating department which employed several engineers and technologists. In addition, in several companies, the study team made a point of interviewing persons known to have particularly strong views about the utilization of engineering and technical manpower. In most - but not all - cases, the study team felt that they had interviewed the most appropriate persons in the firm. In general, the sessions which included managers of operating departments were felt to be especially fruitful.

Interpretation of Responses

The study team attempted to reconcile each respondent's statements of opinion, intention, or policy with those of other respondents, and with whatever data were available. For example, in the single firm which professed to treat engineers and technologists identically with regard to promotion possibilities, the proportion of each category in management and supervision was about the same (Firm K, Table 3). Another firm claimed to be hiring mining technologists for positions that formerly were filled by mining engineers. While the study team had no "hard data" to prove that such substitution was occurring, figures showed that hiring of civil engineers (who might also be trained to do mining engineering) and mining technologists went up when mining engineers were hard to get. Several firms asserted that recent increases in the hiring of technologists relative to engineers did not reflect substitution of technologists for engineers, but of formal education for on-the-job training of technologists. In most of these cases, the data revealed that the number of apprentices in relevant areas taken on had been reduced and/or formal company training programs had been cut back or curtailed.

In every session, the study team attempted to form an overall picture of how the firm conceptualized requirements, how it utilized engineering and scientific manpower, the machinery for implementing manpower policy, and the way various factors, e.g. relative wages, affected manpower decisions. On the basis of such "wholistic" views of the manpower policy of these firms, the study team has made a number of generalizations about substitution, which are reported in Section 5.

COVERAGE OF THE SAMPLE

In selecting the sixteen organizations, there was an attempt to have as much variation as possible with regard to industry, geographical location, size and corporate structure. The group included fourteen privately owned firms and two semi-autonomous government related organizations. The undertakings ranged in size from three with under 750 employees to six with over 20,000. The Head Offices were in three provinces, but some operations of the group were carried on in every province. The industries represented were Pulp and Paper, Chemical, Petroleum, Steel, Aircraft, Electronics, Electrical Equipment, Mining, Motor Vehicles, Construction, Transportation, Utilities and Consulting Engineering.

The sixteen organizations have over 250,000 employees in total; about 7,500 engineers; 1,500 physical scientists; and 3,500 technicians and technologists. By concentrating on major employers of engineers - only three of the sixteen organizations have less than 200 engineers - it was possible to cover more than one-sixth the number of engineers recorded in the Canada Department of Manpower and Immigration 1967 Survey of Engineers and Scientists.

The median values of some of the relevant variables are shown in Table 1, along with the third and fourteenth ranked values - to eliminate from consideration some of the extreme observations. The median value of technicians and technologists per 100 engineers is 43, and only two firms had ratios above 100. The table shows also that engineers and technologists were much more heavily represented than scientists, and that technicians with a two-year (Ontario equivalent) certificate were much less numerous than technologists with three-year diplomas.

TABLE 1

MEDIAN VALUES OF OBSERVATIONS
AMONG SIXTEEN FIRMS, 1970

(Third and Fourteenth Ranked Values Included)

	Low (Third)	Median	High (Fourteenth)
Employees	700	16,500	26,000
Engineers	150	340	900
Scientists	10	40	140
Technologists and Technicians	30	160	400
Diploma Technologists (3 yr.)	5	60	220
Certificate Technicians (2 yr.)	0	10	25
<u>Ratios (x 100)</u>			
Engineers/Employees	1	6	20
(Technologists + Technicians)/ Engineers	10	43	100
Diploma Technologists/ Bachelor Engineers	6	17	95

Since the sample included a small number of firms which were not randomly selected, the generalization of conclusions to the whole of Canadian or Ontario engineering manpower is unwarranted. Nevertheless, a large number of engineers were covered, and in the absence of alternative sources of information, the conclusions of this study may be looked upon with great interest.

THE CONCEPT OF SKILL SUBSTITUTION

The concept of substitution between factors of production, or more generally, between different methods of production lies at the heart of economic theory. The basic notion is that for a given state of technology, there are alternative ways of organizing production, and profit-maximizing entrepreneurs choose those methods, or factor combinations, which minimize costs of production. In this context, substitution between factors or methods is viewed as an adaptation to changes in the relative costs of the different factors. As relative prices change, there is a tendency to use more of the factor whose price has fallen, and less of the one whose price has risen. This is substitution.

Until quite recently, the attention of economists has been focussed on one type of factor substitution, that between aggregate labour and capital. Recently, there has been more of a tendency to look upon labour as hetergeneous and to consider the possibility of substitution between different types of labour.

To consider substitution between different types of labour, it is necessary to consider the difficult question of defining those "different types of labour." Most commonly categories of labour are distinguished by formal educational attainment, or by occupation. The latter contains many difficulties, as occupations may be defined with reference to educational attainment, work function, certification by an official agency, or some combination of the three.

The two occupations considered in this study, engineer and technologist/technician, are notoriously difficult to define. In this study, the occupations are defined in terms of formal educational attainment or its equivalent. The use of the educational criterion was not an inconvenience, since the major concern of this study is the extent to which graduates of the three-year technology programs of the CAAT are viewed as potential competitors of bachelor graduates in engineering.

The basic question then is the extent to which employers attempt to alter the relative numbers of engineers and technologists employed in response to changes in the relative wages of the two groups, which in turn should be related to changes in the relative numbers of the two groups offering their services on the labour market. It should be emphasized that the type of substitution in question here is that which occurs in response to changes in relative wages - and not as a result of changes in technology or in the product composition. Of course all three (and other) types of changes are apt to occur simultaneously, and distinguishing among them is no easy task.

The Process of Substitution

The case study approach enables one to investigate the process of substitution more deeply than does the econometric approach. By "process" is meant the observable actions of employers and employees which bring about the substitution and the constraints on these actions. Two general types of processes may be distinguished:

(i) Educational Substitution: A given set of tasks generally performed by persons with a particular type of education (e.g. Bachelor in Engineering) is transferred to persons with a different type of education (e.g. Diploma in Technology), without a significant change in the functional nature of the tasks, or in the technology.

If this kind of substitution is made on a large scale within a short period of time, it might suggest that labour was not deployed efficiently in the first place, with regard to the match between education and work function. This description represents an "ideal type" which will be only approximated in reality. Normally, the substitution will be accompanied by at least some minor changes in work functions and some additional education and/or training.

(ii) Functional Substitution: The set of tasks performed by persons with a particular type of education (e.g. Bachelor in Engineering) undergoes a functional re-organization, and some of these tasks are transferred to persons with another type of education (e.g. Diploma in Technology). Generally, the functions which are transferred are routinized and become the main work function in a highly specialized job.

Functional substitution often involves the "downgrading" of particular functions through routinization, development of specialized equipment, or maturation of a technology. The downgrading of the educational requirements for computer programming is a familiar example. Often the downgraded function was only one of many functions carried out by the person who first had the responsibility, but becomes the principal activity in a more specialized occupation. The person who has given up the main follow-through of the task is likely to retain responsibility for supervising.

Career Substitution

These descriptions of substitution pertain to the alternative staffing arrangements for accomplishing particular work at a point in time. Skilled manpower often tend to follow a systematic career path in which they move to different types of work over time. In many, perhaps most, cases, educated persons are hired with a view toward their career paths and ultimate positions of responsibility rather than for the specific work functions they will be carrying out when hired.[10] Engineers would seem to be a good example. Educational substitution may occur through substitution of technologists for engineers at a particular point in the engineer's expected career, e.g. for functions which the engineer is expected to be engaged in early in his career; or through replacement along the entire career path. This suggests a third category of substitution processes:

(iii) <u>Career Substitution</u>: A person with one type of education begins to follow a <u>career path</u> that has been regarded as typical for people with a different type of education. The former is intentionally recruited for this career path to the same extent as is the latter.

The second sentence in the above definition indicates that the situation involves more than just the exceptional technologists, once he demonstrates unusual competence, being placed in the engineers' career development stream. In career substitution, the two groups are regarded as perfect substitutes during recruitment, and one would expect that the variance in recruiters' preferences between groups would be less than that within groups. The propensity toward career substitution should not depend upon changes in technology or work functions. In contrast to career substitution, ordinary educational or functional substitution should enable one group (engineers) to <u>accelerate</u> movement along its career path, and thus lead to a widening in the observed gap between average responsibility levels of the two groups.

FINDINGS OF THE STUDY

Recent Trends in the Ratio of Technologists/Technicians to Engineers

The study team was interested in discovering whether in the last few years there had been a substantial increase in the ratio of technologists/technicians to engineers as an increasing number of the former have been turned out by the community colleges. Some observers have argued that Canada, and particularly Ontario, has had a critical shortage of technicians and technologists relative to engineers:[11] and that employers would quickly raise their ratios to a higher plateau when large numbers of diploma techologists appeared on the labour market.

Table 2 indicates the relationship between the ratio of gross or net additions of technicians and technologists to engineers (marginal ratio) and the current ratio of the firm's stocks of technicians and technologiest to engineers (average ratios) for 1968 and 1969. The letter H refers to cases where the marginal is higher than the average, i.e. the average ratio is increasing. In most cases, the relationships are the same for new hires or net additions, but they can differ if the attrition rates vary between engineers and technicians.

An upward trend in the average ratios is slightly more common than a downward trend. However in only three cases is there an unambiguous upward trend in both ratios for the two years. The evidence among these technically sophisticated and progressive firms in Table 2 supports few, if any, generalizations. However the fact that not even half of the cells contain H's at least indicates there was not a universal move to a higher plateau in the utilization of technicians and technologists relative to engineers.

The net additions of technologists (defined in terms of the three-year diploma) were substantially greater than of technicians (defined in terms of the two-year certificate). In many cases, it was not possible to distinguish between the two groups. However,

TABLE 2

COMPARISON OF AVERAGE AND MARGINAL
RATIOS OF TECHNOLOGIST AND TECHNICIAN TO ENGINEER

H: Marginal Exceeds Average
L: Average Exceeds Marginal
=: Marginal = Average
.: Data not available

FIRM	1968		1969	
	New Hires	Net Additions	New Hires	Net Additions
1	L	L	H	H
2	L	L	L	L
3	H	H	H	H
4	H	H	H	H
5	.	H	.	H
6	L	L	.	L
7	H	H	H	H
8	L	L	L	L
9	.	.	.	.
10	L	L	L	L
11	=0	=0	=0	=0
12	=0	=0	=0	=0
13	H	H	L	L
14	.	.	.	.
15	=	H	=	H
16	H	H	L	L

the distinction was found to be important, and generally it was the technologist only, and not the technician, who was regarded as a potential substitute for the engineer. Moreover, while technologists seemed to be highly regarded by employers, many refused to consider hiring any of the two year graduates.

GENERALIZATIONS ABOUT SUBSTITUTION

Negligible Career Substitution

Technologists were almost never regarded as career substitutes for engineers. This occurred in only one of the sixteen firms. This is firm K in Table 3, the only firm in which the proportion of engineers that were in management was the same as the proportion of technicians and technologists in management.

In many firms engineers were hired particularly for their management potential, and their careers and upward mobility were carefully planned by the employer. In contrast, technologists were hired mainly for specific jobs. Although exceptional technologists have moved into higher levels of responsibility, diploma technologists as a group were not treated as a pool of future management as were graduate engineers. In most firms, graduate engineers literally were placed in a pool and were moved throughout the firm during their first year or two, while technologists were put directly into a specific position. In several firms, engineers were hired exclusively for their management potential, and there was no indication that they would ever practice engineering. Technologists were never hired in these kinds of situations.

The lack of career substitution can be traced to perceived differences in the ability and training of the two groups and to issues of social status which may be described under the heading of the "iron ring" ethic. Most firms appeared to believe that engineering graduates have a greater ability to adapt to new challenges and responsibilities and a broader educational base upon which to build for future development than do technologists. One might say that they perceived the probability of locating people with supervisory and management potential to be substantially greater within the group of engineers than within the group of technologists. Judging from observed behaviour, they may feel that among technicians and technologists, this probability is too small to justify the costs of searching for and nurturing this talent.

TABLE 3

PROPORTIONS OF ENGINEERS AND TECHNOLOGISTS
IN SALES & MARKETING AND MANAGEMENT & SUPERVISION
IN 9 FIRMS

(those for which complete data was available)

FIRM	Sales and Marketing		Management and Supervision	
	Bachelor Engineers	Diploma Technologists	Bachelor Engineers	Diploma Technologists
A	-	-	17	-
B	5	-	39	-
C	19	12	5	-
D	8	15	44	9
E	18	12	13	-
F	-	-	39	4
G	8	-	33	-
H	-	-	32	-
I	5	-	13	-
J	13	-	29	-
K*	8	-	7	7

Note: The letter code for identifying firms bears no relationship to the number code used in Table 2.

- less than 5 per cent.

*This was, in fact, the firm that claimed to treat diploma technologists as potential career substitutes for engineers.

Social Resistance Barrier

Some respondents admitted that, in addition to these judgements about ability and education, tradition, social resistance, and lack of information about technologists (as such decisions are usually made by engineers, rarely by technologists) also played an important role in limiting career substitution. There is no way of estimating the importance of the social resistance barrier relative to the other factors, but the study team felt the former to be a significant obstacle to career substitution - though not to functional substitution. These factors probably work in tandem. A low view of the potential ability and of the quality of the education of a technologist can be either the cause of or the result of social rejection of technologists. Social resistance may be manifested through a strong organization of engineers.

Technologists in Sales and Marketing

Some evidence of an indirect nature can be obtained by looking at the proportion of engineers and technologists that are in sales and marketing. In many - but by no means all - fields, respondents stated that the knowledge and skill provided in an engineering education were not really necessary for sales and marketing. There is a widespread belief that in many areas technologists possess the knowledge and skill for this activity, and that the first breakthrough for them will be in sales and marketing.

Table 3 shows the proportions of engineers and of technologists and technicians in sales/marketing and management/supervision for nine firms. In three of the firms, more than five percent of technologists and technicians are in sales and marketing, and in one firm the proportion is greater for technicians/technologists than for engineers. Penetration by technicians and technologists into sales and marketing appears to be slightly greater than into management and supervision. Yet, that penetration is still very little in these firms.

In the view of the study team, overcoming the social resistance barrier will take a long time, but progress will accelerate after a number of technologists have demonstrated the ability to perform as well as engineers in positions of high-level supervisory and management responsibility. However, so long as there is an ample supply of engineers - regardless of the relative supplies of technologists and engineers, and relative wages - it is unlikely that technologists will be given this chance. There are certainly no strong financial incentives to do so, as will be discussed later.

Insofar as the need to have sufficient potential management manpower in the pipeline is one factor influencing the demand for engineers, the increased availability of technologists is likely to have little impact, except in helping speed up the graduate engineer's upward movement through the firm.

Most Substitution of the Functional Type

The substitution of technologists for engineers almost always involved functional re-organization of the engineer's work. In most cases, certain of the engineer's functions were routinized, often geared to a computer, and became the major work of a specialized technologist. One might say that these functions were "downgraded" rather than the technologist being upgraded to the equivalent of an engineer. Examples of this occurred through the computerization of design of electric motors, the computerization of process control in chemical plants, and through standardization and modular design of communications systems. In one case of computerization of design, the work of seven engineers was taken over by one engineer, twelve technologists, and a computer. The supervising engineer was required to have much more skill in mathematics and computer science than any of the seven before, and the technologists were working on a narrower range of tasks than the engineers.

Substitution Usually Related to Changes in Technology

Most substitution of technologists for engineers was dependent upon simultaneous changes in technology. In the view of the study team, it was changes in technology (including the maturation of a technology) rather than the sudden discovery of inefficiency in the deployment of technical manpower or changes in relative wages and/or availability of technologists and engineers that provided the principal stimulus to substitution.

A major functional re-organization usually was necessary in order to allow the substitution of technologists for engineers; and such a degree of functional re-organization generally occurred only along with changes in technology, e.g. computerization, change in type of electric circuitry, change from step-by-step to continuous switching gear, etc. Whether a major re-organization in work functions could occur without changes in technology is hard to say. Probably, in many cases, it could, but the costs of re-organization may be great, and the benefits are usually uncertain.

Re-organization has implications for work responsibility, job and salary analysis, plant layout, seniority, promotion patterns, geographical transfer, and turnover rates. Considerable experimentation may be required before the optimal re-organization is discovered. There may be resistance from employees, unions, and first and second level supervisors.

Large-scale re-organization is likely to be postponed and occur in discrete blocks, irregularly over time. Major changes in technology demand corresponding changes in functional organization, and provide, at the same time, a convenient excuse and setting for organizational changes, even those not directly related to the change in technology.

This finding is consistent with the results of another study, which reported that job design could be treated as technologically given, as it was altered only in case of extreme changes in labour market conditions.[12]

Technology is the Main Determinant

The relative demand for engineers and technologists appears to be influenced mainly by the state of technology and very little by the relative availability of engineers and technologists. The extent to which employers were able to substitute technologists for engineers was constrained by the current technology, and given that technology, by the difficulties of making major re-organizations in work functions.

Peter Doeringer and Michael Piore have observed in a case study of technological change that relative availabilities of different types of labour generally had little influence on choice of technology, equipment, and design of plant.[13] They gave several reasons for this, and the present study corroborates their findings with respect to engineers and technologists. The most important reasons common to both studies are:

(i) Variation in relative numbers of different types of labour is not likely to have a significant effect on over-all costs. Some evidence is given the next section to show that variation in the relative wages of engineers and technologists probably accounts for less than one percent of the total wage bill for the firms studies here.

(ii) The precise estimates of manning costs are too expensive and subject to too many errors to warrant the effort which they would require.

(iii) It is hard to specify what the manning requirements will be after full adaptation. The ultimate job design often comes about through trial-and-error.

(iv) It is difficult to define the jobs before the technology is implemented; and, it is often impossible to estimate the wages before job definition and evaluation.

(v) Organizational factors such as the separation of operating from non-operating divisions and the gap between personnel departments and industrial engineering departments.

In brief it appears that the relative availability of engineers and technologists had no effect on the choice of technology, plant design and layout, and equipment; but the latter choices put tight limits on the potential substitutability between engineers and technicians. Within these limits the amount of substitution that actually took place depended very much upon the financial incentives, generally found to be less than the study team had anticipated - as will be discussed in the section below. In addition, there were several barriers to substitution, dealt with later.

Lack of Financial Incentives to Substitution

According to the theory being considered, changes in relative supplies of technologists and engineers should induce substitution by causing changes in relative wages. Given both the tendency of employers to view the hiring of highly qualified manpower as a form of investment in capital, and the institutional barriers to functional re-organization, one should not expect the demand for engineers and technicians to be influenced much by short-run variation in relative wages.

The scant evidence available suggests that the ratio of starting salaries of diploma technologists to those of bachelor engineers has varied little in the short-run or long-run over the past fifteen years. The starting salaries paid by one large employer of technologists and engineers are shown in Table 4. Though this pertains to only one firm, there is some reason to believe that these ratios are representative of the durable goods manufacturing industry.

Technologists' starting salaries have ranged from 79 per cent to 88 per cent of engineers' starting salaries, but two-thirds of the values are between 82.5 per cent and 85.5 per cent. The ratio was nearly the same in 1953, 1962 and 1970.[14]

If this variation in starting salaries were assumed to apply to all engineers and technologists in employment, then the variation in salary ratios in Table 4 would be negligible in terms of over-all costs. In the sample covered in this study, engineers and technologists made up about 8 per cent of the total number of employees (median). If their wages and salaries were double the average, they would comprise 16 per cent of the wage bill. Suppose that technologists' wages varied from 75 per cent to 85 per cent of engineers' wages, and the latter averaged $10,000. Without substitution, this would correspond to variation of about 4 per cent in the payments to engineers and technologists, or less than one per cent of the total wage bill.

Of course, the gap between the salaries of engineers and technologists is likely to be greater in mid-career than at the time of entering the labour force. A re-organization of work functions that enables the firm to use 45-year-old technologists in place of 45-year-old engineers may offer greater financial benefits than appear likely

TABLE 4

STARTING SALARIES PAID BY ONE FIRM
TO NEW GRADUATES IN TECHNOLOGY AND ENGINEERING

Year	(1) Engineer Starting Salary (Monthly)	(2) Technologist Starting Salary (Monthly)	(3) Ratio = ((2)/(1)) x 100
1953	$297.00	$254.00	85.5
1954	300.00	256.00	85.4
1955	310.00	270.00	87.2
1956	345.00	300.00	87.9
1957	380.00	315.00	82.9
1958	380.00	315.00	82.9
1959	390.00	319.00	81.9
1960	405.00	335.00	82.7
1961	405.00	338.00	82.9
1962	415.00	350.00	84.3
1963	435.00	365.00	83.9
1964	450.00	380.00	84.4
1965	485.00	390.00	80.4
1966	525.00	415.00	79.0
1967	575.00	470.00	81.7
1968	600.00	495.00	82.5
1969	610.00	505.00	82.7
1970	635.00	535.00	84.3

Source: Private records of the firm.

in Table 4. If 25-year-old technologists can be used in place of 45-year-old engineers, the savings are even greater.

Equal Pay for Equal Work

However, a major limitation on the financial advantage of substitution is the tendency toward job definition and evaluation and equal pay for equal work. This factor certainly limits the financial benefits of career and other educational substitution, as defined above. In many firms the argument heard was, "if we have to pay the same salary for this job, we may as well hire the engineer." Others though were cautious about "over-qualification" and emphasized the benefits in terms of morale and productivity from having the appropriate match between worker qualifications and job responsibilities.

This limitation arises mainly when technologists are put on tasks generally done by engineers; and engineers continue on these tasks, i.e. the tasks are open to both groups simultaneously. When functions are transferred (downgraded) from engineers to technologists in block, the potential savings are greatest. A good example of this was provided by an electrical products firm which turned the whole operation of writing specifications for hardware in customers' systems from engineers over to technologists. This change required considerable planning and took several years to complete. It was made possible to some extent by changes in technology.

Other Barriers to Skill Substitution

Several barriers, or factors which impede skill substitution, have already been noted: social resistance, inflexibility of salary schedules, and the difficulties of institutional re-organization. In addition, the study investigated the influence of two other related factors - professional organization in the firm and the Professional Engineers' Act of Ontario.

Professional organization within the firm generally acted as a barrier to career and educational substitution. In most large firms there was a clear demarcation between professional staff (which covered technologists); and a technologist could not do an engineer's work without going on professional staff, and it was nearly impossible for a technologist to go on to professional staff without attaining, or nearly attaining, professional engineering certification. Where the technologists were unionized, such movement was even more difficult. While no official engineering unions were encountered, the engineers in several firms had strong professional organizations which maintained pressure against educational, and to a lesser degree, functional, substitution. This pressure appeared to be greatest in those firms where the engineer's opportunity for upward mobility was least and consequently there was a greater tendency for technologists to be perceived as a threat. In the firms where most engineers went into management, there was little pressure against substitution.

Professional Engineering Registration

The study team had expected to find that the requirements of the Professional Engineers' Act of Ontario would limit all types of substitution of technologists for engineers. In fact, professional certification in itself seemed to have almost no impact on substitution. Functional substitution could take place without any regard for professional certification, except in certain hazardous areas of construction design, and in some types of consulting and technical sales. The stress placed upon professional certification in the latter two fields is probably, to a large extent, a consequence of social resistance and pressure of engineers' organizations, and unrelated to the Professional Engineers' Act.

With regard to educational and career substitution, professional certification appeared to have a slight impact. In most cases technologists cannot go into professional staff (like engineers) without attaining P.Eng. certification. In the view of the study team, however, the real barriers are as noted above - social resistance, pressure of engineers' organizations, and judgements about the ability of the average technologist and the quality and breadth of his education. The technologist who has attained professional certification has overcome these barriers, and professional certification is taken merely as a surrogate for the other accomplishments - in the same way that employers use the A.P.E.O. certification criteria for evaluating foreign degrees. Professional registration was not needed by those who possessed engineering degrees, and most firms did not know which of their engineers were registered.

Lack of Recognition of Technologists: An Additional Barrier

In spite of the fact that technology programs in the community colleges have been going on for over a decade, many firms still had little knowledge of the existence and potential of technologists and technicians. Even among the large and progressive firms interviewed in this study, several had only recently learned about the variety of manpower available from the community colleges and were just now beginning to contemplate how these people might fit into the organization. Most firms were still having trouble finding the right niche for the technologist, and there was much concern that technologists generally reached a career ceiling early in their working life.

The Effect of Absolute Labour Supplies

While relative supplies of engineers and technologists available appeared to have little influence upon the numbers of each demanded, the level of absolute supplies was important in two ways.

Absolute Shortage of Engineers

Most of the cases where substitution of technologists for engineers occurred without simultaneous changes in technology were in those areas where the absolute numbers of engineering graduates have been very low recently - mainly mining, geology, and metallurgy. Career substitution as well as functional substitution has been occurring in these disciplines, and mining technologists were often starting in the types of positions in which mining engineers used to commence their careers. The barriers to substitution appeared to be weakest in the disciplines where the number of graduating engineers was fewest.

This might be taken to suggest that more substitution would take place if employers were forced by an absolute shortage of engineers to do so. It is impossible to say what the limits of substitution are, but it should be borne in mind that the present study was carried out during a period of ample supply of most types of engineers (except mining, metallurgy, and geology). This observation has important implications for the durability of the study team's conclusions (see Conclusions).

The Speed of Adjustment to New Technology

It has been argued above that technology - not relative supplies - is the main determinant of the desired ratio of technologists to engineers. However, the availability of technologists in absolute numbers appears to have influenced the speed of convergence to the desired ratio following a change in technology. Substitution in response to a change in technology occurred more rapidly when trained technologists were available on the market than when they had to be trained by the firm. However, there was no reason to believe that the ratio of technologists to engineers obtained after a complete adjustment to a change in technology would have been higher if the production of technologists had been accelerated.

CONCLUSIONS

Generalizability of Findings

The sample of sixteen firms has been described above and could in no sense be considered random. The firms were exceptionally progressive, acutely concerned about questions of highly qualified manpower utilization, and leaders in their respective industries. Yet it is precisely because of their interest in manpower policy and the fact that they are so well known and highly regarded by job seekers and placement personnel that one might expect the substitution of technologists for engineers to have gone furthest in these firms. In fact, "pure supply effects" were found to have been relatively minor in these firms. Any generalizations from such a sample are perilous, but the study team can think of no good reasons for believing the type of pure supply effects in question to have been substantially greater throughout the rest of industry.

The Relation to Findings of Other Studies

As noted earlier, there has been very little systematic research on substitution between different types of labour in general, and almost nothing on substitution between engineers and technologists. On a general level, the finding are consistent with those of Doeringer and Piore - one of the best studies of its kind - that relative supplies or wages of different types of labour have little influence on investment decisions.[15] The findings are consistent also with the general tendency in manpower economics to assume that substitutability between different types of manpower is near zero - although as noted above, this practice rests more on expediency than evidence. Further, the findings are consistent with the debate among technical educators and engineering manpower commentators in the United States about the optimal ratio of technologists to engineers. In that debate, the optimum usually has been portrayed as a function of technical factors (varying by industry), and rarely dependent upon relative wages or supplies.[16]

There remains, however, the apparent contradiction between the findings of this study and the econometric study by one of the authors, described earlier. This is not the place for a detailed critique of the econometric study, but three points should be made. First, as observed earlier, there were deficiencies in the data used in the econometric study. The census categories, engineer and technician, were not rigorously defined, and there was strong reason to believe that many of those counted as engineers were really technicians. This alone would go far in accounting for the high estimate of the elasticity of substitution between these two categories estimated in that study.

Secondly, the econometric study showed only that there was an inverse correlation across the provinces between the ratio of technicians to engineers and the corresponding relative wages, and it did not indicate the direction of causality. The study revealed that in general the wealthier provinces tended to have both fewer technicians per engineer and a smaller gap between the wages of the two groups than did the poorer provinces. This correlation may indicate only that engineers' earnings were relatively less in the wealthier provinces, because they were in relatively greater supply in those provinces than in the poorer provinces. In other words, because of the identification problem, the results may not have given a good estimate of the derived demand function for engineers and technicians, let alone described the ex ante substitution function.

The elasticity of substitution obtained in the econometric study was so high that for some observers it may withstand even these two strong qualifications. In that case, one is faced with the situation where two different approaches to the question yield contradictory answers. Which answer is to be preferred then depends upon which methodology is to be preferred. This problem has arisen frequently in economics, but there is still no clear cut answer. People may not behave as they say they behave. On the other hand, the fact that a certain theory of behaviour is consistent with some empirical observations does not necessarily make it true. To resolve these issues ultimately, what is needed is more work along both avenues. In the meantime, the above two limitations of the econometric study must be regarded as serious. Moreover those results may describe only the tendency toward a very long run equilibrium. In the opinion of the study team - until other information is available - the findings of this micro-study should take precedence over those of the econommetric study.

Implications for the Demand for Engineers

The study indicated that the expansion of the CAAT, by itself, is not likely to have much impact on the number of engineers that industry desires to hire. In the absence of changes in technology, technologists are likely to move into positions formerly held by engineers only in fields where the absolute number of engineering graduates falls short of demand; e.g. as in mining recently.

The expansion of the CAAT should, however, make the manpower adjustment to technical change more rapid and smooth. In this connection, the study has highlighted the importance of technological change in influencing engineering manpower requirements and has underscored the need for more study of these aspects of technological change.

One final caution is necessary. This study was carried out during a period when most types of engineers were in ample supply. A number of respondents argued that more substitution of technologists for engineers than has taken place is technically possible. However, there is not always an incentive to carry substitution to extremes, and there are, as noted, several barriers to substitution. The conclusions herein rest on the assumption that these conditions, particularly what has been termed social resistence to substitution, will persist. In the opinion of the interviewers, substitution would be carried to anywhere near its extreme potential only if there was a drastic reduction in the absolute number of graduate engineers turned out in spite of however great the expansion of the diploma technology program may be.

NOTES

1. For example, J. Tinbergen and H. Correa, "Quantitative Adaptation of Education to Accelerated Growth" (Kyklos XV, 1962) and J. Tinbergen and H. C. Bos, "A Planning Model of Education Requirements of Economic Development" in The Residual Factor and Economic Growth (Paris: OECD, 1964).

2. For constructive criticism, see R. G. Hollister, A Technical Evaluation, pp. 47-53; A. K. Sen, "Economic Approaches to Education and Manpower Planning" (Indian Economic Review, April, 1966). An interesting model in which there is an attempt to allow for substitution is I. Adelman, "A Linear Programming Model of Educational Planning: A Case Study of Argentina" in I. Adelman and E. Thorbecke (eds.) The Theory and Design of Economic Development (Baltimore: Johns Hopkins, 1966).

3. M. Blaug, "Approaches to Educational Planning" (Economic Journal, June, 1967).

4. The conclusions of the most ambitious study undertaken thus far, that of J. D. Sargan in Richard Layard (ed.), Qualified Manpower and Economic Performance: A Study in the Electrical Engineering Industry (Higher Education Research Unit, London School of Economics, forthcoming).

5. M. L. Skolnik, "An Empirical Analysis of Substitution Between Engineers and Technicians in Canada" (Relations Industrielles, April, 1970). This study contains a discussion of some of the difficulties of using production function analysis on this question. The approach used is a modified version of that developed by Professor Zvi Grilliches in "A Note on Capital-Skill Complementarity" (Review of Economics and Statistics, November, 1969).

6. Of course one can make cross-section comparisons; e.g. of ratios of technicians to engineers, without applying econometric tools.

7. The classic reference is, F. Machlup, "Marginal Analysis and Empirical Research" (American Economic Review, September 1946), pp. 534-5. Machlup was responding particularly to studies of pricing practice by the Oxford Economists Research Group which shed considerable doubt as to the validity of the marginal cost theory of pricing.

8. An excellent example of the fresh insight that a case study can provide is M. J. Piore, "On-the-job Training and Adjustmentment to Technological Change" (Journal of Human Resources, Fall 1968). On the basis of his case studies, Piore describes some heretofore unrecognized advantages of seniority and suggests an entirely different view of structural unemployment from the conventional theory.

9. Joan Robinson, "Capital Theory Up-to-Date", (Canadian Journal of Economics, May, 1970), p. 315.

10. M. Blaug, M. H. Peston, and A. Ziderman, The Utilization of Educated Manpower in British Industry, (London: Oliver and Boyd, 1967).

11. This is the view of the Report of the Select Committee on Manpower Training (Ontario Legislature, 1963).

12. L. E. Davis, R. R. Cantes, and J. Hoffman, "Current Job Design Criteria" (Journal of Industrial Engineering, Vol. 2, 1955).

13. Peter B. Doeringer and Michael J. Piore, Internal Labour Markets, Technological Change and Labour Force Adjustment (MDTA Contract Report No. 38-64, U.S. Department of Labor Manpower Administration, Harvard University, mimeo, 1966).

14. It is difficult to say how these starting salary figures relate to the relative annual numbers of graduates, since the data on the non-university sector are so poor. The Dominion Bureau of Statistics reports the numbers of graduates in the three-year Diploma Technology programs annually for 1960-61 through 1968-69, but the course titles have changed frequently; some programs have changed from two (three) year to three (two) year; and the coverage of institutions has changed, to name just a few of the limitations. Nevertheless, we have constructed a series of ratios of (three-year) Diplomas in Engineering and Science Technology to Bachelor's Degrees in Engineering and Applied Science for Ontario, 1970-69; shown in the following table.

TABLE 5

RATIO OF DIPLOMAS IN TECHNOLOGY TO
BACHELOR'S DEGREES IN ENGINEERING*
ONTARIO 1960-61 to 1968-69

Year	$\frac{\text{Diploma Technology}}{\text{Bachelor Engineering}} \times 100$	Ratio of Starting Salaries
1961	50	83
1962	48	84
1963	51	84
1964	66	84
1965	64	80
1966	71	79
1967	41	82
1968	37	83
1969	59	83

Source: Column (1): D.B.S. 81-209.
Column (2): From Table 4.

These salary ratios have shown little sensitivity to admittedly rough estimates of relative numbers coming on to the labour market, although the gradual decline in the salary ratio during 1964-66 is at least in the right direction. However, if the figures on graduates for 1967 and 1968 are correct, then the upward sluggishness of the salary ratio suggests the market was not at work. Of course, the firm in question may be a monopsonist, but a comparison of its engineering salaries with other sources of data suggests that in hiring engineering graduates it moves closely with other employers.

15. See note 13 above.

16. For a brief summary of this debate, see M. L. Skolnik, "An Empirical Analysis of Substitution", pp. 287-88. This assessment of the debate is the author's.