Article

"An Empirical Analysis of Substitution Between Engineers and Technicians in Canada"

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An Empirical Analysis of Substitution Between Engineers and Technicians in Canada

Michael L. Skolnik

The author analyzes substitution between engineers and technicians through the application of a derived demand equation model to 1961 Census data and concludes that there is considerable substitution between these groups. The conclusion is qualified by noting certain weaknesses of the data. The results should be viewed in the context of the importance of subtitution for manpower and educational planning and the lack of empirical study to date.

Introduction

In the manpower forecasting approach to educational planning, the possibility of substitution between different skills has generally been ignored. Most of the theoretical and empirical work has been based upon the notion of fixed skill coefficients determined by technology [1]. Recently, the assumption of technological rigidity has come in for some

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[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,* OECD, Paris, 1964.

criticism [2]. In spite of the importance of this topic, however, to date there has been very little systematic empirical study of skill substitution, and the numerous international comparisons of occupational distributions and occupational coefficients have not focussed on substitution [3].

The purpose of this paper is to investigate skill substitution by a cross-section study of occupational data, from regions of Canada. The analysis concentrates on two occupations, the engineer, and the engineering and scientific technician. Engineers and technicians are, for the most part, products of different types of training programs, with differing costs of training. Yet, there are some *a priori* grounds for believing that these two categories of highly skilled manpower can be substituted for one another, although there is no empirical evidence of this point.

Although skill substitution appears to be an interesting and important question for study, it is difficult to pin down empirically. The present study is a modest attempt to estimate substitution by a new method, and the results are only approximate. These results should be viewed in the context of the importance of questions of substitution for manpower and educational planning and the lack of empirical study to date. It is hoped that this rudimentary attempt will stimulate further interest in the problem.

The Concept of Skill Substitution

Skill substitution is taken to mean substitution between different types of labour, defined according to worker traits, abilities, education and training, etc. Analytically, skill substitution may be divided into two categories. First, there is *functional* substitution. Different techniques of production may require different work functions, and the variation in functions may involve variation in educational requirements. Once the

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2 R.G. Hollister, « The Economics of Manpower Forecasting, » *International Labour Review,* April 1964, and *A Technical Evaluation of the First Stage of the Mediterranean Regional Project,* OECD, Paris, 1966. A.K. Sen, « Economic Approaches to Education and Manpower Planning, » *Indian Economic Review,* April, 1966. The implications of skill substitutibility for manpower planning have been discussed at length by Hollister in these works, also by M. Blaug, "Approaches to Educational Planning », *Economic Journal,* June, 1967.

3 R. G. Layard and J. C. Saigal, « Educational and Occupational Characteristics of Manpower : An International Comparison, » *British Journal of Industrial Relations,* July, 1966; M. A. Horowitz, M. Zymelman, and I. L. Hernstodt, *Manpower Requirements for Planning: An International Comparison Approach,* Northeastern University, Boston, December, 1966; and J.G. Scoville, *The Occupational Structure of Employment,* 1960-1980, I.L.O., Geneva, August, 1966. (Mimeo).

technique of production is specified, there is less scope for variation in the nature of jobs, although some change in ancillary operations is possible, and job design may be altered by recombining elemental tasks in different ways. Secondly, given the nature of the functions dictated by the existing technology and job design, there may be *educational* substitution, that is, variation in the educational background required to perform certain functions.

These two types of substitution are interrelated. Often, the substitution between people with different educational qualifications requires simultaneous adjustment of technology or job design [4]. Moreover, educational substitution may require training on the job. If this training is considerable, then the process is less one of substituting one category of labour for another than of transferring a *person* of one category to a different category.

In addition to the possible need for training and complementary alteration of work functions, substitution may be limited by institutional constraints, such as trade union regulations or certification requirements, which prevent, or at least discourage, otherwise qualified people from transferring to different jobs.

After defining the relevant types of labour, or skills, the concept of skill substitution can then be considered as a special case of general factor substitution. The most common index of substitution is the elasticity of substitution which, in the two-factor case, relates a proportionate change in the radio of two factors employed to a corresponding change in their price ratio, along a constant-output curve. Skill substitution differs from ordinary capital-labour substitution in that the underlying production model contains more than two factors of production. Therefore the appropriate elasticity of skill substitution must be defined for the situation with more than two factors. In the n-factor case, there are a number of definitions to choose from, different mainly in respect of (1) the variables which are held constant and (2) the number of variables which are involved in the experiment [5].

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[4] For a brilliant discussion of the mutual adaptation between technology and skill, see Michael J. Piore, « On-the-job Training and Adjustment to Technological Change. » *Journal of Human Resources,* Fall, 1968.

[5] Yair Mundlak, « Elasticities of Substitution and the Theory of Derived Demand », *Review of Economics and Statistics,* 35 (1968). See also D. McFadden, « Production Functions with Constant Elasticities of Substitution », *Review of Economic Studies,* 30 (1963).

For our purposes the traditional definition, the Allen partial elasticity of substitution, is mathematically the most convenient and empirically the most meaningful, and we shall use the expression elasticity of substitution to refer to the Allen measure [6]. However, even this measure has proven difficult to estimate, as will be discussed later on.

Technicians vs. Engineers : The Optimal Ratio

There has been considerable debate among educators, professional and technical societies and personnel managers concerning the relative need for technicians as opposed to engineers. This dialogue has not been conducted within the framework of the manpower planning model, but has consisted mainly of *ad hoc* answers to two questions : how can the existing stock of scientific and technical personnel be utilized more efficiently and what types (and in what quantities) of scientific and technical graduates should the educational system be turning out ?

Nearly all participants to this debate have agreed upon two fundamental points. First, most observers acknowledge that the some extent technicians and engineers could be substituted for one another.

Secondly, most of those who have commented on this type of substitution have agreed that there is an *optimal* radio of technicians to engineers, for an industry and for a country [7]. However, only rarely has the optimal radio been said to be in any way related to the relative costs of training, or wages of engineers and technicians.

Most of these assertions about the optimal ratio of technicians to engineers have been simply impressionistic but a few have been based on limited empirical data about the possibilities of substitution.

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6 Defined in R.G.D. ALLEN, *Mathematical Analysis for Economists,* London ' MacMillan, 1938, pp. 340-3. For a discussion of how it is generalized to the n-factor case, see Robert M. Solow, « Some Recent Developments in the Theory of Production », in M. Brown (ed), *The Theory and Empiral Analysis of Production* New York : National Bureau of Economic Research, 1967.

7 One of the earliest statements of this type is contained in the famed Wickenden-Spahr Report which recommended a ratio of 2.3 technicians per engineer. William F. Wickenden and Robert H. Spahr, *A Study of Technical Institutes.* Society for the Promotion of Engineering Education, 1931, Ratios of four or five to one are more commonly heard in recent years, e.g., H. Russell Beatty, « The Role of the Technical Institute in the Next Decade », *IRE Transactions on Education,* March, 1958 ; John Merrill, « The Scientific Manpower Shortage and Its Implications for the Engineering Technician », *IRE Transactions on Education,* February 1960. Both educators and industrialists talk of ratios in the same range, although the ratios suggested by Heads of Technical Institutes are often higher than these advanced by Deans of University Engineering Schools.

The work that engineers do has been broken down into those tasks that could, as well, be done by technicians and those tasks that could be done only by engineers. One typical study of this type in the U.S. indicated that about 64% of the engineer's work (in terms of time) could be done by technicians [8]. The inference drawn from this is that the U.S. could make do with one-third of the number of engineers that it is employing, given adequate supporting staff. There are limitations to this type of study, concerning the divisibility of time spent in supervision and other tasks and the differences in the quality and reliability between engineers and technicians on the same tasks. Although no data on cost ratios have been integrated with these work study results, it is generally assumed that engineers are more expensive to produce than technicians — and, thus, it is the engineer's time that is to be economized [9].

The Definition and Classification of Engineers and Technicians

The science and engineering technician occupies a position in industry that is intermediate between the professional engineer and the tradesman with regard to duties and generally with regard to formal education as well [10]. At the upper and lower levels of the technician category, the dividing line is not precise between technicians and engineers on the ont hand, and tradesmen on the other. The lower boundary is especially ambiguous, as the majority of today's technicians have come up from the ranks of tradesmen and at a given time many are in the process of moving up. Moreover, the word « technician » is of little help in defining the category, since many of the titles in the *Dictionary of Occupational Titles* which contain this word belong outside the category (e.g., sound technician) and many titles which describe the work of engineering technicians do not contain the word (instead, e.g., assayer, tester, chemist, expert, etc.) [11]. Certification by the appropriate examining body cannot be used as a criterion,

[8] Merrill, « The Scientific Manpower Shortage and Its Implications for the Engineering Technician ».

[9] Although there are no detailed studies of comparative costs of training engineers and technicians, it is generally true that the engineer has a longer formal post-secondary education (4 or 5 years) than tre technician (2 or 3 years). However, very little is known about the amounts and costs of on-the-job training, which may be considerable, especially for technicians.

[10] For a discussion of the technician's marginality, see William M. Evan, « On the Margin — The Engineering Technician », in Peter L. Berger, *The Human Shape of Work,* New York, The MacMillan Co., 1964.

[11] Compare the descriptions of the « electronics technician» and « electronic technician ». The former appears to be a skilled tradesman. Volume 1, p. 246.

since only a small fraction of those who would fit under a narrow functional definition have membership [12]. Although the official certification body in Ontario stipulates that a technician should have at least grade 12 (plus other formal requirements), in 1961, 37.4% of the technicians in the Census had not gone beyond grade 11.

The distinction between high-level technicians and engineers is usually made on the basis of formal qualifications. An engineer is generally defined as having a university degree in engineering or accreditation by the Association of Professional Engineers. However, technicians sometimes do work that is usually regarded as engineers' and may even supervise engineers ; and engineers may spend much time in work that could as well be done by technicians. Moreover, the best technology diploma courses may turn out more hightly qualified graduates than some of the engineering schools [13].

There is reason to believe that a substantial number of technicians were counted as engineers in the 1961 Census of Canada and that the extent of overstatement of the number of engineers relative to technicians varied between Provinces. Over a quarter of the engineers in Canada in the Census did not possess a university degree, although only a small percentage of those who have attained P.Eng. status have done so without a degree [14]. In the remainder of this section, we will illustrate how the distinction between technicians and engineers in the Census may vary among Provinces. On the basis of this analysis, dummy variables will be constructed for use in the empirical analysis in the next section.

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[12] Although the 1960 Census of the U.S. counted 850,000 technicians, the Institute for the Certification of Engineering Technicians had issued only 1,663 certificates as of February, 1964. At the same time the Ontario Association of Certified Engineering Technicians and Technologists had certified about the same absolute number, whereas the 1961 Census counted about 17,000 for Ontario. See Merritt A. Williamson, « Certification of Engineering Technicians », *Journal of Engineering Education,* July-August, 1964, p. 404.

[13] In Ontario the highest level below the professional engineer is called engineering technologist, but the Census does not distinguish between tecrnologists and technicians. In Europe, the term « technologist » sometimes denotes equivalent status to professional engineer. See Hugh Warren, *Vocational and Technical Education* (Paris : UNESCO), 1967, Chapter iv.

[14] The only data available are from direct communication with the Association of Professional Engineers of Ontario and pertain only to the annual intake of new members rather than to the total membership. In recent years the proportion of new entrants into the ranks of P. Eng. who have qualified by examination has been between three and four percent of the annual intake, and this includes some with a university degree which is not accredited. The A.P.E.O. may have a larger base than the Census, however, since the former includes many who are probably classified under teaching or management in the Census.

Table 1 contains the proportionate educational attainment of technicians and engineers by region for Canada in 1961. There is a substantial difference between Ontario and the West with regard to the proportions of technicians and engineers who have completed four to five years of high school or some university. Ontario has substantially higher proportion of its engineers in these categories and a lower proportion of its technicians [15]. Ontario also has a lower ratio of technicians to engineers, 0.87, than the West, 0.97 (Table 4). Might it be the case, then, that some people with four to five years of high school or some university in the West are counted as technicians and in Ontario as engineers although doing essentially the same work and having the same actual qualifications ? To answer this question would require a detailed investigation of classification practices in industry in Ontario as compared to the West.

TABLE 1 — PROPORTIONATE EDUCATIONAL ATTAINMENT LEVELS OF ENGINEERS AND TECHNICIANS CANADA, 1961

	Atlantic	Quebec	Engineers Ontario	West	Canada
University Degree	61.3	76.4	67.9	78.9	72.2
Some University	12.8)	10.8)	11.0)	9.1)	10.7)
	) 20.1	) 17.8	) 23.9	) 15.4	) 20.3
High School, 4-5	7.3)	7.0)	12.9)	6.3)	9.6)
None to High School, 3	18.6	5.8	8.2	5.7	7.5
	Atlantic	**Quebec**	**Technicians Ontario**	**West**	**Canada**
University Degree	4.5	5.7	4.2	4.5	4.7
Some University	19.2)	16.3)	17.3)	26.0)	18.9)
	) 44.2	) 42.2	) 60.7	) 64.3	) 57.9
High School, 4-5	25.0)	35.9)	43.4)	38.3)	39.0)
None to High School, 3	51.3	42.1	35.1	31.2	37.4

15 One of the biggest limitations of the 1961 Census of Canada was that no provision was made for respondents to acknowledge formal education beyond secondary school that was not in a university. It is most likely that people who had attended post-secondary technical institutes circled grade 12 (or 13) as the highest level of schooling attained although some may have marked the « some university » category.

We can, however, shed some light on this question indirectly. In Table 2A we see that, of the total number of technicians and engineers with four to five years of high school or some university, 31% are technicians in Ontario and only 20% are technicians in the West. This could be a true classification, i.e., perhaps many fewer of the technical personnel with a university degree have attained the Association of Professional Engineers Certificate in engineering in the West than in Ontario. Alternatively, this discrepancy could be due merely to differences in classification procedures. Suppose that the distribution of technical personnel with four to five years of high school or some university was the same for the West as for Ontario. Then, the actual ratio of technicians to engineers in the West would be 0.82, less than Ontario's ratio (see Table 2B). If the correct distribution for the West were midway between what was observed for Ontario and for the West, then the actual ratio of technicians to engineers in the West would be almost identical to that in Ontario. Using this approach we constructed dummy variables consisting of ones and

TABLE 2 — COMPARAISON OF RATIOS OF TECHNICIANS FOR ALTERNATIVE ASSUMPTIONS ABOUT CLASSIFICATION OF TECHNICAL PERSONNEL WITH HIGH SCHOOL, 4-5, OR SOME UNIVERSITY

A. Persons with High School, 4-5 or some University classified as Technicians of Engineers

	Ontario		West[a]		West[b]		West[c]	
	No.	%	No.	%	No.	%	No.	%
Technicians	4,715	31	1,331	20	2,075	31	1,673	25
Engineers	10,376	69	5,362	80	4,618	69	5,020	75
	15,091		6,693		6,693		6,693	

B. Ratio of Technicians to Engineers in the West for alternative assumptions about the classification of persons with High School, 4-5, and some University between Engineer and Technician categories

	Ratio : (T/E)
Ontario	0.87
West[a]	0.97
West[b]	0.82
West[c]	0.89

[a] Actual.
[b] Assuming Ontario's percentage distribution between technicians and engineers.
[c] Assuming a percentage distribution midway between that of Ontario and the West.

zeros, as a Province's ratio of technicians to engineers was likely to be under — or over — estimated relative to the national average.

Empirical Evidence on Substitution between Technicians and Engineers in Canada

International Comparisons

Table 3 contains figures on the ratio of technicians to engineers for Canada, the U.S., and some European countries. Canada's ratio of technicians to engineers is quite near that of the U.S., less than 1:1, and substantially less than the European figures. A variety of *ad hoc* theories might be constructed to explain this variation. Perhaps industry can absorb nearly any combination of engineers and technicians, and the relatively greater output of engineers in the richer countries reflects consumption preferences, or social demand (i.e., supply), rather than differences in the technological conditions of demand. If this were the case, one might expect to find Russia further down the table. Or perhaps more weight should be attached to differences in industry's demands, and the more technologically sophisticated a country, the greater its relative need for engineers. For this interpretation we might wish Germany's ratio to be smaller. However, the ratios have been increasing within most of these countries while, presumably, all were becoming more technologically sophisticated. Perhaps, much of the variation is due to differences in classification and definition.

Interregional Comparisons

Turning to the Canadian data (Table 4), we see again the tendency for the ratio[15a] of technicians to engineers to be lowest in the wealthiest and most technologically advanced Provinces — Ontario, British Columbia and Alberta ; and the highest in the poorest and least technologically developed Provinces — Newfoundland and Prince Edward Island. Here again there are exceptions to this relationship, as Manitoba and Saskatchewan have higher incomes than Nova Scotia and New Brunswick. If we group the four Atlantic and four Western Provinces, respectively, then the correlation between the technician-engineer ratio and family income stands out more clearly.

[15a] In calculating these ratios we have used the Census category « science and engineering technicians not elsewhere specified », which consists of over 170 different job titles, but specifically excludes medical and dental technicians, draughtsmen, and surveyors. It is impossible to seperate science from engineering technicians, but engineers often direct science technicians.

TABLE 3 — NUMBERS OF SCIENCE AND ENGINEERING TECHNICIANS AND ENGINEERING

	Engineers (1)	Technicians (2)	Ratio (2)/(1)
Canada[a]	43,066	39,822	0.92
U.S.A.[b]	853,738[c]	275,072	0.32
U.S.S.R.[b]	1,236,000	1,157,000	1.74
France[b]	140,000	340,000	2.42
Germany[b]	74,741	189,676	2.53
Great Britain[b]	100,800	N.A.	(4.20)

[a] Derived from the Census of Canada, 1961, and includes figures for the Yukon and the Northwest Territories.

[b] References given in William M. EVAN, « On the Margin — The Engineering Techician », in Peter L. BERGER (ed), *The Human Shape of Work*, New York : MacMillan Company, 1964. The reference periods are U.S.A., 1960 ; U.S.S.R., 1960 ; France, 1954 ; Germany, 1956 ; Great Britain, 1959-60. The latter country's figure is ased on a survey of seleted industries, rather than on census data.

[c] For some reason this figure cited by Evan excludes females. The total for males and females was 860,949.

TABLE 4 — NUMBER OF TECHNICIANS, ENGINEERS AND MEAN FAMILY INCOME BY PROVINCE, 1961

	Engineers	Technicians	Ratio T/E	Mean Family Income
Ontario	19,729	17,104	.87	5,868
British Columbia[W]	3,356	3,113	.93	5,618
Alberta[W]	3,042	2,778	.91	5,602
Quebec	12,514	11,780	.94	5,387
Manitoba[W]	1,261	1,452	1.15	5,260
Saskatchewan[W]	945	1,025	1.08	4,803
Nova Scotia[A]	1,011	1,034	1.02	4,260
New Brunswick[A]	735	734	1.00	4,155
Prince Edward Island[A]	56	69	1.23	3,919
Newfoundland[A]	341	567	1.66	3,673
[W]Western Region	8,604	8,368	.97	5,421
[A]Atlantic Region	2,143	2,404	1.12	4.072

Note : The total is slightly less than in Table 3, because figures for the Yukon and the Northwest Territories are not included here, and some engineers and technicians were not classified by region.

The Measurement of Substitution

Direct estimation of elasticities of substitution from the production function when there are more than two factors is possible, but it has not been attempted in this study for two reasons. First, the methods of estimation that are available impose very restrictive *a priori* conditions upon the coefficients. In H. Uzawa's first generalization of the CES function to the n-factor case, the necessary condition is that the elasticity of substitution between any pair of factors is identical to that between any other pair [16].

This condition would make it impossible to tell whether the substitution between technicians and engineers was greater or less than substitution between these and other factors. In Uzawa's second generalization the conditions are less imposing, but still rather strong ; here the factors are partitioned into sets, with the elasticity of substitution between any pair of factors from the same set being identical and the elasticity between factors from different sets always being unity [17].

In addition to the restrictive nature of the constraints on the elasticities, there is a further problem of the inadequacy of the data. This problem is not unique to our enquiry into technician-engineer substitution ; for, as Professor Zvi Griliches has noted,

> ...questions about the relative size of elasticities of substitution are... usually very hard to answer on the basis of ordinary economic data. As far as the production function is concerned the elasticities are second order parameters and hence almost impossible to estimate [18].

Griliches goes on to suggest that the derived demand equations are more promising for empirical studies of substitution, since in these equa-

[16] H. UZAWA, « Production Functions with Constant Elasticities of Substitution », *The Review of Economic Studies,* 30 (October, 1963). See also M. Brown, *On the Theory of Measurement of Technological Change,* Cambridge University Press, 1966, Appendix B.

[17] Professor Solow has remarked that, in the attempt to develop constant elasticity of substitution production functions for the empirical study of substitution, the three- or n-factor case has thus far proved « unrewarding ». See his « Some Recent Developments », pp. 44-45.

[18] Zvi GRILICHES, « A Note on Capital-Skill Complementarity », *Review of Economics and Statistics* II, 4, Nov. 1969, pp. 465-468.

tions the elasticities of substitution are first order parameters. In this section we will apply the derived demand approach developed by Griliches [19] to the data on engineers and technicians.

The starting point is to form the derived demand equations, with all the variables measured in logs, and the inputs defined per unit of output (assuming constant returns to scale) :

$$\left.\begin{array}{lr} T = a_1 + \eta_{TT}W_T + \eta_{TE}W_E + \eta_{TL}W_L + \eta_{TK}R & (1.1) \\ E = a_2 + \eta_{TE}W_T + \eta_{EE}W_E + \eta_{EL}W_L + \eta_{EK}R & (1.2) \\ L = a_3 + \eta_{TL}W_T + \eta_{EL}W_E + \eta_{LL}W_L + \eta_{LK}R & (1.3) \\ K = a_4 + \eta_{TK}W_T + \eta_{EK}W_E + \eta_{LK}W_L + \eta_{KK}R & (1.4) \end{array}\right\} (1)$$

Here T,E,L, and K refer to technicians, engineers, other labour, and capital, respectively, W_T denotes the wages of technicians, etc., and R is the price of capital. The η_{ij}'s are the price elasticities, and $\sum_i \eta_{ij} = 0$. Also $\eta_{ij} = v_j \sigma_{ij}$ where v_j is the share of the j-th factor in total costs and the σ_{ij}'s are the Allen elasticities of substitution.

Unfortunately, data on capital by Province comparable to that on technicians, engineers, and other labour was not available, and so equation (1.4) was dropped, along with the last term on the right side of the other three equations. This means that in measuring substitution among the other three factors, variation in capital is not controlled statistically. Estimates obtained from the three-equation model could be biased insofar as they consist of points from three-factor iso-surfaces corresponding to different levels of capital per unit of output. The extent of such bias would depend upon the regional variation in capital intensity

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19 This ingenious approach is derived in Griliches' earlier paper, « Notes on the Role of Education in Production Functions and Growth Accounting », a paper presented at the Conference on « Education and Income » of the Conference on Research in Income and Wealth, Madison, Wisconsin, November 15-16, 1968. Griliches used this approach to test the hypothesis that skilled labour is more complementary with physical capital than unskilled labour. The analysis presented in the Conference paper is extended, both theoretically and empirically, in « A Note on Capital-Skill Complementarity ».

and the ease of substitution between capital and the various types of labour [20].

Applying the conditions, $\sum_i \eta_{ij} = 0$, and making some algebraic manipulations to equations (1) we derive (2):

$$\left.\begin{aligned} \ln\left(\frac{T}{L}\right) &= b_1 + v_T\,(\sigma_{TT} - \sigma_{TL})\ \ln\left(\frac{w_T}{w_L}\right) + v_E\,(\sigma_{TE} - \sigma_{EL})\ \ln\left(\frac{w_E}{w_L}\right) \quad (2.1) \\ \ln\left(\frac{E}{L}\right) &= b_2 + v_T\,(\sigma_{TE} - \sigma_{TL})\ \ln\left(\frac{w_T}{w_L}\right) + v_E\,(\sigma_{EE} - \sigma_{EL})\ \ln\left(\frac{w_E}{w_L}\right) \quad (2.2) \end{aligned}\right\} (2)$$

If the ease of substitution between technicians and engineers is greater than that between either one and other labour, we would expect positive coefficients for the second independent variable in (2.1) and the first independent variable in (2.2). At the same time one would ordinarily expect the other coefficients to be negative. In this case, then, since $\sigma_{TE} > \sigma_{TL}$ and $\sigma_{TE} > \sigma_{EL}$ it follows that $\sigma_{TE} > 0$, i.e., technicians and engineers are substitutes in the absolute sense [21]. This might seem like a trivial hypothesis. However, the alternatives, i.e., that the requirements of each fixed ($\sigma_{TE} = 0$) or that the two skills are complementary ($\sigma_{TE} < 0$), are also plausible, and, in fact, the former is one of the underlying assumptions of the manpower planning model.

These equations were estimated for Canadian industry using the 1961 Census data on numbers employed and average wages of technicians,

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[20] This could be a seroius source of bias if the amount of capital varies systematically with the utilization of technicians and engineers. This would be the case if the replacement of one type of labour by another involved the use of additional capital. See Finis Welch's argument that even if factors A and B are not substitutes, A may be a substitute for a combination of B and some other factor C, *Journal of Human Resources,* Summer, 1969. Unfortunately, estimates of capital by province are not available. I have constructed a set of estimates, but they performed poorly — probably because of the invalidity of the assumptions upon which they were based. On the other hand, even if capital were included in the analysis there would be a bias from the « vintage effect » as discussed in G.C. Harcourt, « Biases in Empirical Estimates of Elasticities of Substitution », *Review of Economic Studies* 33 (1966).

[21] See R.G.D. ALLEN, *Mathematical Analysis for Economists,* pp. 503-509.

engineers, and other labour for nine Provinces[22] and three industrial sectors.

The data on numbers employed were available for aggregate non-farm industry, for two-digit industrial groups, and for three-digit manufacturing industries. However, for most of the two- and three-digit groups, the numbers in some cells were too small to expect reliable results. Moreover, the data on wages were available only for aggregate production and not by sector or industry. Finally, to allow for Provincial differences in the classification of engineers and technicians (see pp. 290-4), two sets of dummy variables were constructed.

Since the largest proportion of both technicians and of engineers are employed in manufacturing, the first set of regressions were run for aggregate manufacturing. The results are given in Table 5. All of the coefficients have the expected signs, but because of the small sample size (n = 9) the results are statistically significant only when dummy variables are included.

TABLE 5 — TEST FOR SUBSTITUTION BETWEEN TECHNICIANS AND ENGINEERS, AGGREGATE MANUFACTURING, CANADA, 1961

n = 9

Dependent Variable	Coefficient of $\ln(W_T/W_L)$	Coefficient of $\ln(W_E/W_L)$	R^2	F	Dummy
ln T/L	−2.94 (2.03)	2.76 (2.74)	.30	1.21	0
ln T/L	−2.75 (1.69)	3.75 (2.33)	.60	2.47	1
ln T/L	−2.57 (0.74)	3.40 (1.01)	.92	19.69	11
ln E/L	1.06 (2.98)	−3.87 (4.03)	.27	1.12	0
ln E/L	1.41 (1.91)	−2.06 (2.60)	.75	5.05	1
ln E/L	1.62 (0.81)	−2.90 (1.10)	.96	35.49	11

22 Excluding Prince Edward Island.

In an effort to obtain a larger sample, a set of regressions were then run on the observations from three two-digit groups — manufacturing, mining, and transportation and utilities — for the nine Provinces (n = 27). These results, given in Table 6, show that the coefficients have the expected signs, and the regressions (though not all of the individual coefficients) are statistically significant, without dummy variables [23].

TABLE 6 — TEST OF SUBSTITUTION BETWEEN TECHNICIANS AND ENGINEERS, THREE TWO-DIGIT SECTORS BY NINE PROVINCES(N = 27), CANADA, 1961

Dependent Variable	Coefficient of ln (W_T/W_L)	Coefficient of ln (W_E/W_L)	R^2	F
ln T/L	−3.89002 (1.72277)	2.27881 (2.11396)	.42	8.67
ln E/L	.384917 (1.36154)	−3.89487 (1.67071)	.65	22.72

These results suggest that technicians and engineers are absolute substitutes (i.e., $\sigma_{TE} > 0$), but they do not give a numerical value for the coefficient. This was satisfactory for Professor Griliches' application of his method, since his main concern was to obtain an ordinal ranking of the various partial elasticities. However, Griliches's method can be used to estimate a lower bound for the value of the *largest* of the elasticity coefficients.

Let C_{ij} denote the coefficient of the j-th term in the i-th equation of (2). Then,

$$\left.\begin{aligned} v_T\,(\sigma_{TT} - \sigma_{TL}) &= C_{11} \\ v_E\,(\sigma_{TE} - \sigma_{EL}) &= C_{12} \\ v_T\,(\sigma_{TE} - \sigma_{TL}) &= C_{21} \\ v_E\,(\sigma_{EE} - \sigma_{EL}) &= C_{22} \end{aligned}\right\} \quad (3)$$

23 The inclusion of dummy variables in this set of regressions had about the same effect as in the regressions reported in Table 5 on the R^2, F, and t values while changing the coefficients only slightly.

Since $\sigma_{TE} > \sigma_{TL}$ and $\sigma_{TE} > \sigma_{EL}$ it follows that $\sigma_{TE} > 0$ and at least one of the two cross-elasticities is greater than zero [24]. Using figures for v_T and v_E, we can calculate

$$\left.\begin{aligned} D_1 &= (\sigma_{TE} - \sigma_{EL}) = \frac{C_{12}}{v_E} \\ D_2 &= (\sigma_{TE} - \sigma_{TL}) = \frac{C_{21}}{v_T} \end{aligned}\right\} \quad (4)$$

and compare D_1 with D_2. Since the larger of the two elasticities, σ_{EL} and σ_{TL}, is non-negative, it follows that

$$\sigma_{TE} \geqslant \min (D_1, D_2),$$

i.e., $\min(D_1, D_2)$ is a lower bound for the value of the elasticity of substitution between technicians and engineers.

In calculating D_1 and D_2, there is some question as to which values of v_E and v_T should be used, since they are not constants. As our goal is merely to estimate the lower bound for σ_{TE}, the maximum values of v_T and v_E are apropriate [25]. The maximum values of v_T and v_E respectively, for the larger sample, occur on the same observation (Alberta, mining) and are

$$v_T = 2.64\%$$

$$v_E = 6.35\%$$

Substituting these values in equations (4), with the values of the two coefficients from Table 6, the estimated lower bound for σ_{TE} is 14.6, indicating that technicians and engineers, as they are defined in the Census, are very close substitutes.

Conclusion

The estimate of the lower bound on the value of the Allen elasticity of substitution coefficient between technicians and engineers is much larger than the values usually obtained for capital-labour coefficients in empirical work, and it is difficult to interpret this result. While this value is well above zero (no substitutibility), it is a long way from infinity (perfect substitutibility). *A priori* it seems reasonable that substi-

[24] This is shown in R.G.D. ALLEN, *op. cit.*, pp. 503-509.

[25] I wish to thank Professor Griliches for his advice on this point.

tution between two types of labour may be easier than between capital and labour, but the manpower approach to educational planning has tented to exclude the former possibility. The above analysis suffers from the defects of small sample size and omission of data on capital, but even a large bias would not alter the general conclusion that emerges. That conclusion is that there is substitution between engineers and technicians, and this substitution may be substantial.

ÉTUDE EMPIRIQUE DES SUBSTITUTIONS INGÉNIEURS-TECHNICIENS AU CANADA

Les prévisions de la main-d'œuvre pour l'orientation de l'enseignement n'a fait aucun cas de la possibilité de substitution entre des professions différentes. La plus grande partie des études théoriques et empiriques est fondée sur l'hypothèse que des professions très précises sont déterminées par la technologie. Les critiques s'en sont pris dernièrement à cette hypothèse de la rigidité technologique. En dépit de l'importance de cette assertion, très peu d'études empiriques et systématiques sur le sujet de la substitution de compétence ont été entreprises jusqu'à présent. Cette étude se veut une recherche bilatérale sur les données occupationnelles dans les provinces du Canada, particulièrement deux professions les ingénieurs et les techniciens scientifiques dont les programmes et les coûts de formation sont, pour la plupart, différents. Nous sommes cependant enclins à penser que ces deux classes de main-d'oeuvre très spécialisées peuvent être interverties, bien qu'il n'y ait pas d'évidence empirique le confirmant.

LE CONCEPT DE SUBSTITUTION DE COMPÉTENCE

La substitution de compétence signifie la substitution entre des genres de travail différents, déterminés par les qualifications, les études, l'entraînement et les caractéristiques du travailleur, etc. Pour fins d'analyse, on divise en deux classes la substitution de compétence. En premier lieu, la substitution fonctionnelle est celle qui se produit lorsque des techniques différentes de production exigent des fonctions différentes, impliquant des différences quant à l'éducation requise. L'autre genre de substitution, étant donné la nature des fonctions dictées par le travail et la technologie correspondante, est la substitution conditionnée par la formation, c'est-à-dire les antécédents académiques exigés pour occuper tel poste. Ces deux formes de substitution sont interreliées. Il arrive souvent que la substitution de gens ayant des qualifications académiques différentes implique une adaptation simultanée de la technologie. De plus, la substitution selon l'instruction peut demander une formation sur le lieu même de travail. Si cette formation exigée est considérable, ce processus sera beaucoup plus une mutation de catégorie pour une personne donnée qu'une substitution de compétence.

QUESTIONS DE DÉFINITION DU TRAVAIL ET CLASSIFICATION DES TRAVAILLEURS

Le fait que la compétence du technicien et de l'ingénieur puisse être acquise par l'expérience au travail même (parfois complétée par des études à temps partiel), cause des problèmes de définition sérieux. On s'interroge à savoir si ces catégories de compétence doivent se limiter à des qualifications officiellement reconnues, soit diplôme universitaire, diplôme d'école technique ou l'adhésion à une corporation professionnelle; ou si cette classe de techniciens doit comprendre tous les gens capables d'effectuer efficacement le travail en question. Ce problème se double du fait qu'il arrive souvent que les techniciens effectuent du travail considéré comme du travail d'ingénieur et peuvent même parfois diriger des ingénieurs; d'autre part, les ingénieurs peuvent consacrer beaucoup de leur temps à des tâches qui pourraient tout aussi bien être effectuées par des techniciens. De plus, les meilleurs cours de technologie peuvent former des techniciens plus qualifiés que les ingénieurs issus d'écoles de génie plus faibles.

Les données analysées au cours de cette recherche sont celles du recensement de 1961 au Canada, et nous sommes enclins à mettre en doute la valeur des critères utilisés pour la catégorisation d'occupations. Il semble qu'un certain nombre de techniciens ont été comptés au nombre des ingénieurs et que l'ampleur de surestimation du nombre d'ingénieurs varie selon les provinces. Ainsi, plus du quart des ingénieurs varie selon les provinces. Ainsi, plus du quart des ingénieurs canadiens selon le recensement ne possèdent pas de diplôme universitaire, bien que seulement un faible pourcentage de ceux qui ont obtenu le statut d'ingénieur y soient parvenu sans diplôme.

CONCLUSION

La partie empirique de l'étude consiste en une analyse descriptive de la fluctuation du rapport des techniciens aux ingénieurs dans les provinces, suivie d'une évaluation économétrique de la substitution.

Le Canada possède un des plus faibles rapports de techniciens à ingénieurs parmi les pays fortement industrialisés, bien que ce rapport soit plus grand que celui qui existe aux États-Unis. Il semble généralement que plus un pays est riche, moins il y a de techniciens par ingénieurs et cette relation vaut pour le niveau de prospérité parmi les provinces du Canada. La fluctuation considérable du rapport de techniciens par ingénieurs selon les régions nous permet de penser qu'il y a substitution. Cependant, l'évaluation de l'élasticité de substitution dans une fonction de production à plus de deux intrants est très difficile. Griliches [1] a proposé une méthode pour évaluer l'ampleur relative des différentes fluctuations de substitution et son approche de la demande dérivée a été utilisée au cours de notre étude. De plus, nous avons pu utiliser l'approche de Griliches afin d'évaluer une limite inférieure de l'élasticité de substitution entre techniciens et ingénieurs.

L'élasticité de la substitution entre techniciens et ingénieurs semble plus considérable que celle entre techniciens ou ingénieurs et tout autre genre de travail et quelle est plus grande que zéro de façon significative. En fait, nous sommes en mesure de croire que cette élasticité est assez grande.

Ces conclusions doivent être vues en prenant en considération la faible dimension de l'échantillonnage, les doutes sur la véracité des données du recensement et les éventuelles déviations causées par l'omission du facteur capital de l'analyse. Cependant même une grande déviation de ces facteurs ne pourrait modifier notre conclusion générale. Ces conclusions doivent être perçues dans l'optique de l'importance de cette substitution pour les centres de main-d'œuvre, la planification de l'enseignement et en tenant compte du manque d'études empririques antérieures en ce domaine. Nous espérons que cette tentative rudimentaire stimulera l'intérêt pour cette question à l'avenir.

1 GRILICHES, Zvi, « Notes on the Role of Education in Production Functions and Growth Accounting », *Conference on Education and Income,* Madison, Wisconsin, nov. 15-18, 1968.